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REVISED INSTRUCTIONS FOR TI-59 COMBINED CARD/MODULE CALCULATIONS FOR IN-PLANE AND FLEXURAL PROPERTIES OF SYMMETRIC LAMINATES

STEVEN L. DONALDSON

MECHANICS AND SURFACE INTERACTIONS BRANCH
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JUNE 1982

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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is an updated and expanded version of AFWAL-TR-81-4116. It contains descriptions and step-by-step instructions for the simple, combined use of magnetic cards with the composite materials module, designed for use in TI-59 programmable calculators. Users do not have to be familiar with TI-59 programming. These programs contain the key calculations of the stiffness and strength of unidirectional and symmetrically laminated composites, including sandwich core laminates. Both in-plane and flexural loadings can be applied, giving in-plane and flexural response. Instant calculations can be made for practical

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use. With the use of a printer, the results can be immediately and permanently recorded. The equation numbers in this report are from Introduction to Composite Materials by Tsai and Hahn, published by Technomic Publishing Company, Westport, Connecticut, July 1980.

FOREWORD

This report was prepared in the Mechanics and Surface Interactions Branch (AFWAL/MLBM), Nonmetallic Materials Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. The work was performed under the support of Project Number 2419, "Nonmetallic Structural Materials", Task Number 241903, "Composite Materials and Mechanics Technology".

The programs are written for Texas Instruments calculators (TI-59's) to operate with or without a printer. However, the use of a printer is highly recommended. The specially designed "Composite Materials Module" must be installed in place of the standard "Master Module".

This report supersedes AFWAL-TR-81-4116, coauthored by Stella Gates and Stephen Tsai. Many of the programming flow charts and example problems in this report are taken from that original publication.

The equations and table numbers which appear in the flow charts and program descriptions are the same as in Introduction to Composite Materials, by Tsai and Hahn, published by Technomic Publishing Company, Westport, Connecticut, July 1980.

Many thanks to Lisa Wilson for skillfully typing the entire report, and to Stephen Tsai for his willingness to help my understanding and presentation of the material.

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NOMENCLATURE

A_{ij} = laminate in-plane modulus; i,j = 1,2,6
unit ply in-plane compliance; i,j = x,y,s

a_{ij} = laminate in-plane modulus; i,j = 1,2,6
unit ply in-plane compliance; i,j = x,y,s

A^*_{ij} = normalized laminate in-plane modulus; i,j = 1,2,6

a^*_{ij} = normalized laminate in-plane compliance; i,j = 1,2,6

c = half thickness of core in equivalent number of plies (fractional c is allowable)

D_{ij} = laminate flexural modulus; i,j = 1,2,6

d_{ij} = laminate flexural compliance; i,j = 1,2,6

D^*_{ij} = normalized laminate flexural modulus; i,j = 1,2,6

d^*_{ij} = normalized laminate flexural compliance; i,j = 1,2,6

E_i = unit ply engineering constants, i = x,y,s

E^o_i, E^f_i = effective in-plane and flexural Young's and shear moduli; i = 1,2,6

F_{ij}, F_i = strength parameters in stress space; i,j = x,y,s

F^*_{xy} = normalized failure interaction term

G_{ij}, G_i = strength parameters in strain space; i,j = x,y,s

h = total laminate thickness

h_o = unit ply thickness

NOMENCLATURE

$I_\varepsilon, R_\varepsilon$ = strain invariants

M_i = moments; $i = 1,2,6$

N_i = stress resultants; $i = 1,2,6$

n = total number of plies

Q_{ij} = on-axis unit ply modulus; $i,j = x,y,s$

R_t, R_t' = strength ratio roots of quadratic failure criteria

S = unit ply shear strength

S_{ij} = on-axis unit ply compliance; $i,j = x,y,s$

t = distance of outer surface of ply from laminate mid-plane in equivalent number of plies

U_i = invariant linear combinations of unit ply moduli; $i = 1$ to 5

X, X' = unit ply longitudinal tensile and compressive strengths

Y, Y' = unit ply transverse tensile and compressive strengths

ε_i = on-axis strain for a unit ply; $i = x,y,s$
laminate strain; $i = 1,2,6$ $(\varepsilon_i = \varepsilon_i(z))$

$\varepsilon_i^o, \varepsilon_i^f$ = in-plane and flexural surface strain; $i = 1,2,6$

k_i = flexural curvature; $i = 1,2,6$

ν_x = unit ply longitudinal Poisson's ratio

ν_{21}^o, ν_{21}^f = major in-plane and flexural Poisson's ratios

NOMENCLATURE

σ_i = on-axis stress for a unit ply; i = x,y,s
laminate stress; i = 1,2,6 ($\sigma_i = \sigma_i(z)$)

$\bar{\sigma}_i$ = average in-plane stress; i = 1,2,6

$\sigma^{\circ}_t, \sigma^{\circ\prime}_t$ = allowable stresses, in-plane loading

σ^f_i = surface stress, flexural loading; i = 1,2,6

$\sigma^f_t, \sigma^{f\prime}_t$ = allowable surface stresses, flexural loading

θ_t = ply orientation w.r.t. the 1-axis

SECTION I

INTRODUCTION

With the use of the Materials Laboratory composites module and Combo cards, the task of calculating in-plane and flexural strength and stiffness properties can be done on a pocket calculator, namely the TI-59. This is not intended to replace the larger programs for more complex hygroscopic, thermal, and other types of analysis. However, the structural designer now has an ability to quickly evaluate the effects of materials selection, laminate stacking, and hybridization on a composite laminate's properties. That is, he can rapidly calculate the in-plane and flexural stiffness matrices, plot failure envelopes, and calculate strength ratios to show a laminate's load carrying abilities. The laminate properties calculated can then be compared to other laminate properties or even isotropic material properties (such as aluminum) to assist the designer in selecting the material and stacking sequence for the desired overall properties. The turn-around time, cost, and access to large computers are hence avoided. The designer can rapidly evaluate many laminates at his desk or drafting table.

The use of a printing cradle (i.e., the PC-100C) is highly recommended, but not necessary, for using the composites module and Combo cards. The printer quickly writes out input and calculated values for permanent storage. If the printer is not used, numbers must be displayed individually and recorded by hand. All Combos designated with a "P" are compatible with the printer. Users without a printer should find the non-"P" designated Combos are easiest to use.

All input, calculations, and output are done by the calculator using a combination (hence "Combo") of two key elements--the Composite Materials Module, which fits into the back of the TI-59, and a set of magnetic Combo cards read by the calculator. The module consists primarily of subroutines called by the programs stored on the cards. The cards are responsible for data input, proper data storage, selective calling of subroutines from the module, and data output. The module is available from the Materials Laboratory (AFWAL/MLBM) for those seriously interested in using it. The Combo cards can be keyed in, recorded, and labeled by the user with little difficulty. Brief instructions for users not familiar with TI-59 programming are given in Appendix C. Complete listings of the programs for each Combo are given in this report, Appendix D.

The TI-59 calculator has a large amount of memory divided into two parts: program memory, up to 480 steps, and data memory, up to 60 registers. These are the initial values or the partitioning set when the calculator is turned on. All Combo cards use this partitioning. These memory locations are also divided into "banks" as follows:

Bank 1: Program memory, steps 000-239

2: Program memory, steps 240-479

3: Data registers, 30-59

4: Data registers, 00-29

Each magnetic card can record one "bank" per side, or two banks per card. All Combo cards are program steps recorded in banks 1 and 2. When the side of a card is read into the calculator, the bank that is stored on that side of the card replaces the memory (and only that bank) that was in the calculator. Note, then, that reading in a Combo card which is program memory in banks 1 and 2, does not affect the values stored

previously in the data registe .., banks 3 and 4.

Use of the Combo cards is divided into two main steps. First, the user must record individual ply properties in their proer data registers. This is done using Combo 0, 1, or 1P. Next, a laminate program (Combo) 2, 2P, 3, 3P, 4, 4P) is read into the TI-59 and calculates laminate properties using the play data already in the data registers. The only ply properties in the data registers that are recalled by the lamination programs are U_i (i = 1-5) stored in locations 30-34; G_{ij} ($i,j = x,y$) stored in locations 44-49, and h_0 stored in location 59. These quantities are defined in the section describing Combo 0. Note that once Combo 0, 1, or 1P are used to enter ply properties into their proper registers, these registers (specifically, bank 3) can be recorded onto their own magnetic card. If this is not done, a user would use Combo 0, 1, or 1P to record play properties, then read in one of the laminate Combos, hence writing over the 0, 1, or 1P program in the program memory. This is satisfactory if the user only wishes to work with one material. If the user is working with a lamination program and wants to change materials, he would have to re-read Combo 0, 1, or 1P (and hence wipe-out the lamination program), key in the new material (which then replaces the old material properties in the data registers), and re-read the lamination Combo card. This is not always convenient and, in the case of the hybrid Combos 4 and 4P, not workable. Instead, one can use Combo 0, 1, or 1P to store material properties in their proper data registers. Next, these material properties can be recorded onto a separate card by pressing [3] [2nd] [illegible]. * The display will go blank. A blank card should be inserted into the right side of the calculator. This records data registers 30-59 (bank 3) onto the card. Note that two materials can be stored per card, one per side. Now, to run one of the lamination Combos with that material, one needs

* see note, page 4.

only to read in that material card, which stores the properties in bank 3 of the calculator. Note Combos 0, 1, and 1P were not necessary, and the program memory was not distrubed.

The functions of each Combo are listed in the Table of Contents.

This report differs from its predecessor, AFWAL-TR-81-4116, in several respects. The most obvious difference is the addition of detailed explanations describing the use of each of the Combo cards. Sample problems for the non-printing cards have also been added. The old Combo 1 (Selected Ply Data) has been re-named Combo 0, and a new Combo 1 (User input Ply Data) has been added. Combo 1 now serves the same purpose as Combo 1P, except Combo 1 lacks the printing capability. Inconsistencies in the data input method (whether to initialize before or after the first entry) have been removed. Several program flow charts have also been added.

Combos 4 and 4P, hybrid laminates analysis, have a Materials Laboratory Technical Report especially for their use (AFWAL-TR-81-4183). Users of the hybrid technical report should be aware that the old version of Combo 1 and 1P are given at the beginning of the Combo 4 and 4P report. The new Combos 0, 1, and 1P, as listed in this report, are easier to use and will work with Combo 4 and 4P.

Note from page 3: The calculator will not write onto magnetic cards if the calculator is in a "fixed" format display mode (i.e., the number of digits displayed has been previously set). If the display flashes after attempting to record a card, the card did not record. Press CLR INV 2nd [illegible]. This removes the fixed format. Repeat the card recording procedure as before.

SECTION II

COMBO 0: SELECTED PLY DATA WITHOUT PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 0: SELECTED PLY DATA CARD				
Aluminum				
T300/5208	B/5505	AS/3501	Scotchply	Kev 49/Ep

Combo 0 is one of the cards available for storing material ply properties in their correct memory locations so that the laminate in-plane, flexural, or hybrid properties can be calculated using further appropriate Combo cards. Combo 0 is used when the operator is satisfied with the material properties given on pages 24-26. Its primary advantage over Combo 1 and 1P is that a composite material's stiffness and strength properties are recorded in their proper memory locations (bank 3 and 4) by simply pressing one button corresponding to that material (see Figure 1). With the Combo 0 program stored in bank 1 and 2, pressing A, B, C, D, E, or A' calculates and stores the necessary ply values. Therefore, if a new set of material properties is desired, simply press the corresponding button and the old values will be replaced with the new ones. If one of the laminate cards is stored in banks 1 and 2, and new material properties are desired, it would be cumbersome to restore Combo and press A,...., or A' to restore the material properties. It is, therefore, recommended that, especially when using the hybrid laminate cards (Combos 4 and 4P), each material be given its own separate card side as described in the Introduction.

When one of the materials is selected, the Combo 0 program will store its SI properties in the proper locations. If English properties are desired, press $\boxed{E}$ and the material's corresponding English properties will replace the metric ones. This step actually converts and restores U_i and h_0 only. The failure parameters G_{ij}, are dimensionless and hence do not change. Recall that U_i, G_{ij}, and h_0 are the only properties that are recalled by the lamination Combos.

Graphically, the program works as shown in Figure 3. The engineering elastic constants are converted to U_i and the failure properties are converted to the G_{ij}. The program listing for Combo 0 is given in Appendix D. A short description of how to key-in and record a program onto a card is given in Appendix C.

The following steps should be followed to use Combo 0:

1. Press $\boxed{\text{CLR}}$, read side 1, press $\boxed{\text{CLR}}$, read side 2.*

2. Press A, B, C, D, E, or A' depending on which set of material properties are desired (see Figure 1).

The machine then takes the values of E_x, E_y, ν_x, E_s, X, X', Y, Y', S, and F_{xy}^*, calculates, and stores (in the locations given in Figure 2) the following properties:

Q_{xx}
Q_{yy}
Q_{xy}
Q_{ss}

on-axis modulus (Equation 1.12):

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{Bmatrix} = \begin{bmatrix} Q_{xx} & Q_{xy} & 0 \\ Q_{xy} & Q_{yy} & 0 \\ 0 & 0 & Q_{ss} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_s \end{Bmatrix}$$

*To read a card side, slide the card into the right side of the calculator in the direction of the arrow corresponding to the side of the card to be read. Retrieve the card from the left side of the calculator. Handle cards only the the edges.

U_1
U_2
U_3
U_4
U_5

linear combinations of modulus (Equation 3.15):
$U_1 = U_1\ (Q_{xx}, Q_{yy}, Q_{xx}, Q_{ss})$ etc.
used in lamination calculations

G_{xx}
G_{yy}
G_{xy}
G_{ss}
G_x
G_y

dimensionless strength parameters (Equation 7.11 and 7.28). Failure occurs when:

$$G_{ij}\varepsilon_i\varepsilon_k + G_i\varepsilon_i = 1$$

Note that ply thickness, h_o, is also stored. The calculator is now ready to accept any of the lamination Combos.

3. Convert ply data to English units if desired (see Figure 1).

4. Store results from bank 3 onto a separate card (if desired).

Step	Procedure	Press	Display
1	Select Material		
	T300/5208	$\boxed{A}$	216.59641
	Boron/5505	$\boxed{B}$	214.39805
	AS/3501	$\boxed{C}$	130.57541
	Scotchply 1002	$\boxed{D}$	198.05771
	Kevlar 49/Epoxy	$\boxed{E}$	350.87335
	Aluminum	$\boxed{2nd}$ [illegible]	0
2	Convert from SI to English	$\boxed{2nd}$ [illegible]	39.4

Figure 1. Combo 0 Instruction Chart

00	15	30 U_1	45 F_{yy}, G_{yy}
01	16 G_{xx}	31 U_2	46 F_{xy}, G_{xy}
02	17 G_{yy}	32 U_3	47 F_{ss}, G_{ss}
03	18 G_{xy}	33 U_4	48 F_x, G_x
04	19 G_{ss}	34 U_5	49 F_y, G_y
05	20 G_x	35	50
06	21 G_y	36	51
07	22	37	52
08	23 X	38	53
09	24 X'	39	54
10 Q_{xx}	25 E_x, Y	40	55
11 Q_{yy}	26 E_y, Y'	41	56
12 Q_{xy}	27 E_s, S	42	57
13 Q_{ss}	28 ν_x, $F_{xy}{}^*$	43	58
14	29	44 F_{xx}, G_{xx}	59 h_o

Figure 2. Combo 0 Storage Memories

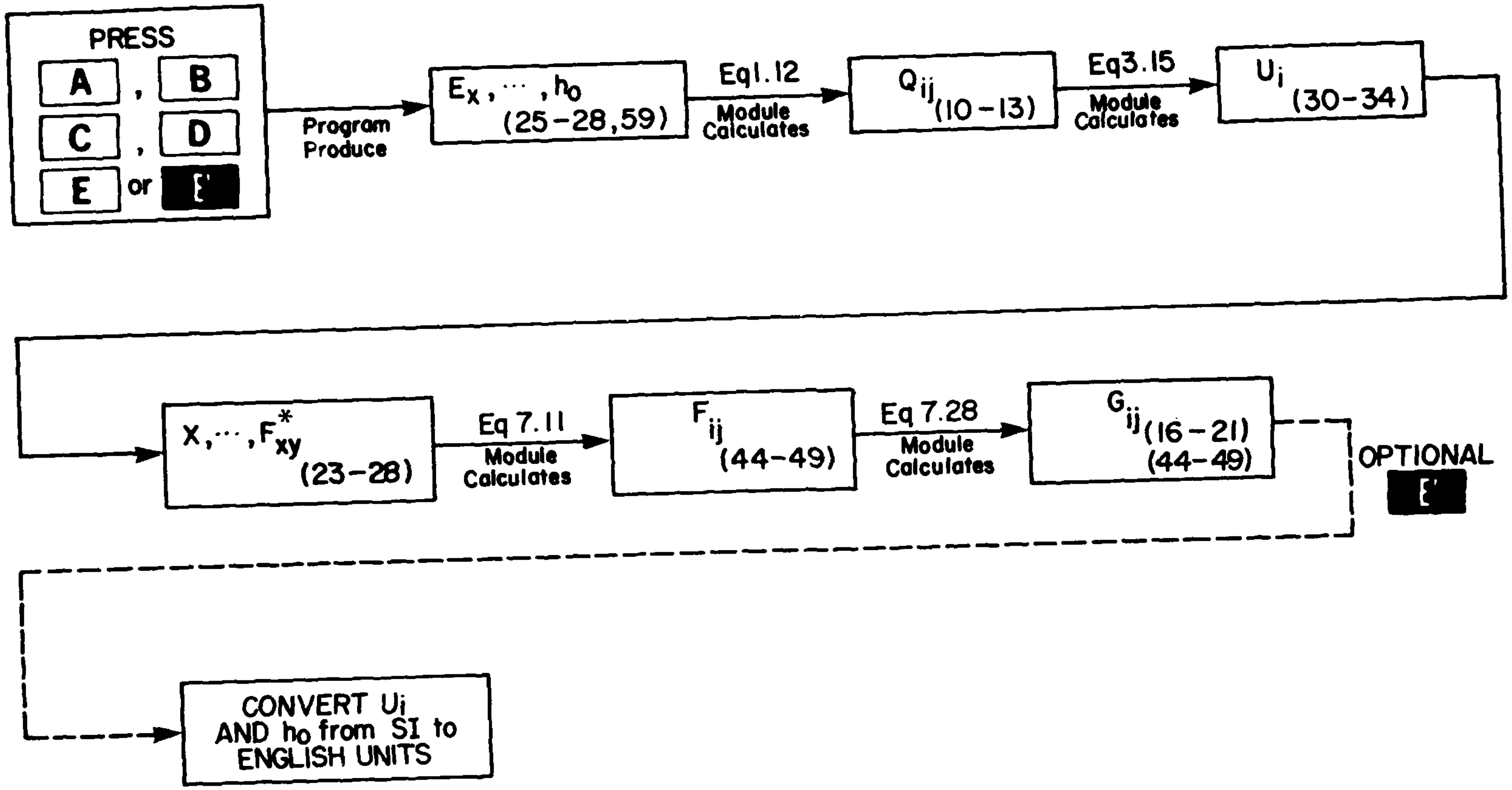


Figure 3. Combo 0 Flow Chart

SECTION III

COMBO 1: USER INPUT PLY DATA WITHOUT PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 1: USER INPUT PLY DATA w/o PRINTER				
Q_{ij}, S_{ij}	U_i	A_{ij}	F_{ij}	G_{ij}
$E_x,\ldots,h_o$	$X,\ldots,F_{xy}^*$	SI→Engl	Engl→SI	

Combo 1 is another one of the cards available for use in storing material ply properties in their correct memory locations (see Figure 6). Once these properties are in the data registers, one of the lamination programs can be read and used. Combo 1 is used when the user wishes to input his own ply data, and no printer is available. The user may input values with SI or English units. Once this is done, all subsequent calculations, including lamination calculations, will be done in the system entered. The systems can be changed as long as the Combo 1 program is still stored by pressing C or D (see Figure 4). As with Combo 0, this changes and restores the U_i and h_o values only. The Combo 1 program listing is given in Appendix D.

This program can be used by following these steps:

1. Press CLR, read side 1, press CLR, read side 2.
2. Enter E_x, E_y, ν_x, E_s, h_o as shown in Figure 4.

The machine calculates:

Q_{xx}, Q_{yy}, Q_{xy}, Q_{ss} — on-axis modulus (Equation 1.12):

$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_s\end{Bmatrix} = \begin{bmatrix}Q_{xx} & Q_{xy} & 0\\ Q_{xy} & Q_{yy} & 0\\ 0 & 0 & Q_{ss}\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_s\end{Bmatrix}$$

S_{xx}, S_{yy}, S_{xy}, S_{ss} — on-axis compliance (Equation 1.9):

$$\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_s\end{Bmatrix} = \begin{bmatrix} & & \\ & Q & \\ & & \end{bmatrix}\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_s\end{Bmatrix} = \begin{bmatrix}S_{xx} & S_{xy} & 0\\ S_{xy} & S_{yy} & 0\\ 0 & 0 & S_{ss}\end{bmatrix}\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_s\end{Bmatrix}$$

U_1, U_2, U_3, U_4, U_5 — linear combinations of modulus (Equation 3.15):

$U_1 = U_1\,(Q_{xx}, Q_{yy}, Q_{xy}, Q_{ss})$ etc.

used in lamination calculations

$A_{xx} = Q_{xx}h_o$

$A_{yy} = Q_{yy}h_o$

$A_{xy} = Q_{xy}h_o$

$A_{ss} = Q_{ss}h_o$

On-axis A matrix for one ply

a_{xx}, a_{yy}, a_{xy}, a_{ss} — inversion of on-axis A matrix for one ply (inversion of previous matrix)

3. Display Q_{ij}, S_{ij}, U_i, A_{ij}, and/or a_{ij} as desired (see Figure 5).

4. Enter X, X', Y, Y', S, Fxy* as shown in Figure 4.

The machine calculates:

F_{xx} F_{yy} F_{xy} F_{ss} F_x F_y	Strength parameters in stress space (Equations 7.11, 7.12, 7.13, 7.15)
G_{xx} G_{yy} G_{xy} G_{ss} G_x G_y	Strength parameters in strain space (Equation 7.28)

The calculator is now ready to accept any of the lamination programs.

5. Display F_{ij} and/or G_{ij} as desired (see Figure 5).

6. Make SI → English or English → SI changes if desired (see Figure 4).

7. Transfer results from storage registers (bank 3) onto one side of a card if desired.

Step	Procedure	Press	Display
1a	Enter E_x	A	4
b	E_y	R/S	3
c	ν_x	R/S	2
d	E_s	R/S	1
e	h_o	R/S	1.1
*			
2a	Enter X	B	5
b	X'	R/S	4
c	Y	R/S	3
d	Y'	R/S	2
e	S	R/S	1
f	F_{xy}*	R/S	1.5
**			
3a	Convert from SI to English	C	h_o (English Units)
b	Convert from English to SI	D	h_o (SI Units)

Figure 4. Combo 1 Instruction Chart

Step	Procedure	Press	Display
*	Display Q_{ij} and S_{ij}	A'	Q_{xx}
		R/S,R/S,...	Q_{yy}, Q_{xy}, Q_{ss}
		R/S,R/S,...	S_{xx}, S_{yy}, S_{xy}, S_{ss}, 1.2
	Display U_i	B'	U_1
		R/S,R/S,...	U_2, U_3, U_4, U_5, 1.3
	Display A_{ij} and a_{ij}	C'	A_{xx}
		R/S,R/S,...	A_{yy}, A_{xy}, A_{ss}
		R/S,R/S,...	a_{xx}, a_{yy}, a_{xy}, a_{ss}, 1.4
**	Display F_{ij}	D'	F_{xx}
		R/S,R/S,...	F_{yy}, F_{xy}, F_{ss}, F_x, F_y , 1.6
	Display G_{ij}	E'	G_{xx}
		R/S,R/S,...	G_{yy}, G_{xy}, G_{ss}, G_x, G_y, 1.7

Figure 5. Combo 1 Options

00	15	30 U_1	45 F_{yy}, G_{yy}
01	16 S_{xx}, G_{xx}	31 U_2	46 F_{xy}, G_{xy}
02	17 S_{yy}, G_{yy}	32 U_3	47 F_{ss}, G_{ss}
03	18 S_{xy}, G_{xy}	33 U_4	48 F_x, G_s
04	19 S_{ss}, G_{ss}	34 U_5	49 F_y, G_y
05	20 G_x	35	50
06	21 G_y	36	51 F_{xx}
07	22	37	52 F_{yy}
08	23 X	38	53 F_{xy}
09	24 X'	39	54 F_{ss}
10 Q_{xx}	25 E_x, Y	40	55 F_x
11 Q_{yy}	26 E_y, Y'	41	56 F_y
12 Q_{xy}	27 E_s, S	42	57
13 Q_{ss}	28 ν_x, F_{xy}^*	43	58
14	29	44 F_{xx}, G_{xx}	59 h_o

Figure 6. Combo 1 Storage Memories

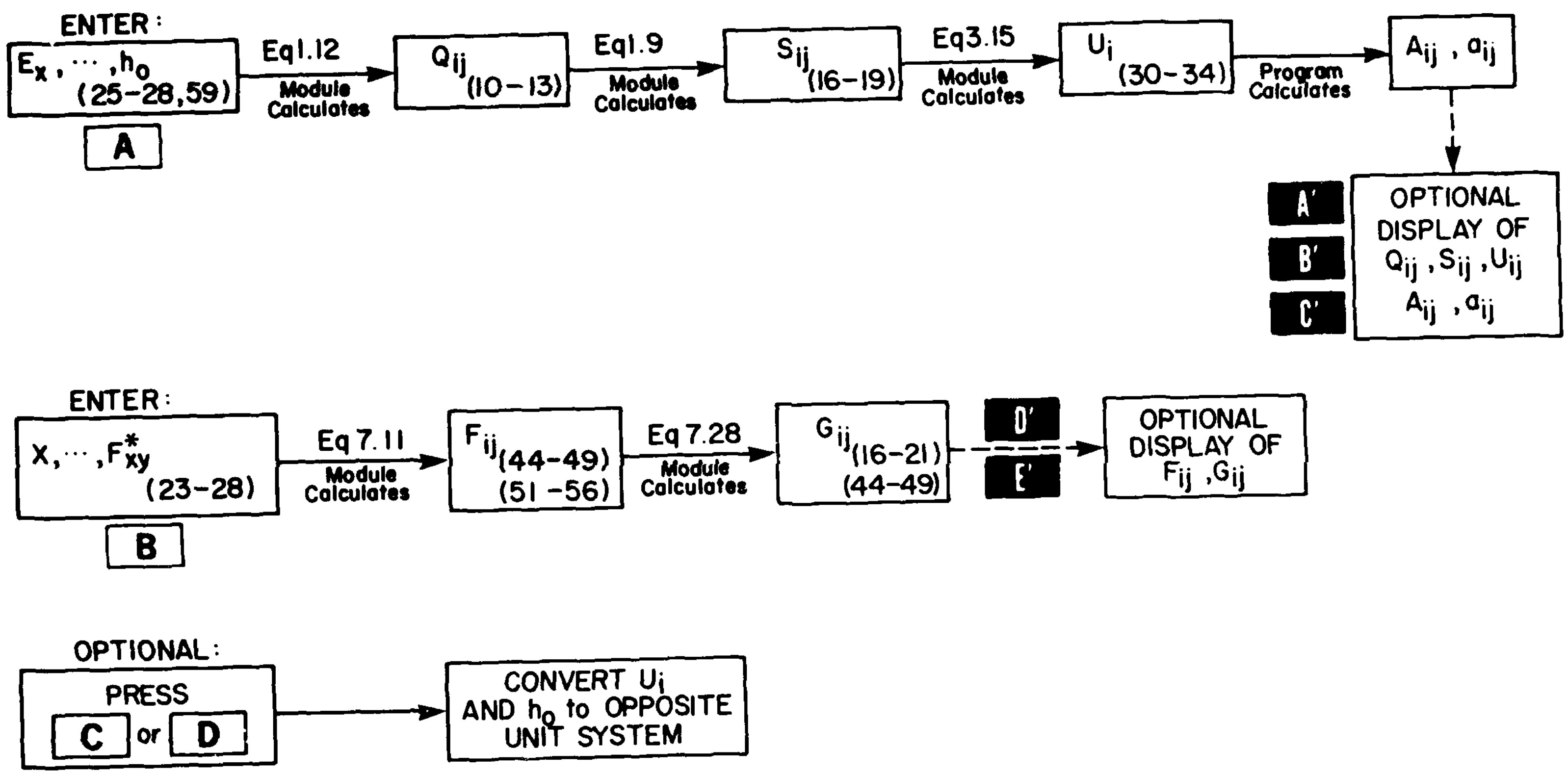


Figure 7. Combo 1 Flow Chart

COMBO 1 SAMPLE PROBLEM: USER INPUT PLY DATA

PROCEDURE	KEY	DISPLAY
Enter E_x (181 E09)	A	4
E_y (10.3 E09)	R/S	3
ν_x (280 E-3)	R/S	2
E_s (7.17 E09)	R/S	1
h_o (125 E-6)	R/S	1.1
Display Q_{ij}	A' R/S " "	181.811 09 10.346 09 2.897 09 7.170 09
Display S_{ij}	R/S " " "	5.525-12 97.087-12 -1.547-12 139.470-12
Display U_i	B' R/S " " "	76.368 09 85.732 09 19.710 09 22.607 09 26.880 09
Display A_{ij}	C' R/S " "	22.726 06 1.293 06 362.116 03 896.250 03
Display a_{ij}	R/S " " "	44.199-09 776.699-09 -12.376-09 1.116-06

PROCEDURE	KEY	DISPLAY
Enter X (1.5 E09)	B	5
X' (1.5 E09)	R/S	4
Y (40 E06)	R/S	3
Y' (246 E06)	R/S	2
S (68 E06)	R/S	1
F_{xy}* (-.5)	R/S	1.5
Display F_{ij}	D' R/S " " " "	444.444-21 101.626-18 -8.360-18 216.263-18 0.000 00 20.935-09
Display G_{ij}	E' R/S " " " "	12.004 03 10.681 03 -3.069 03 11.118 03 60.647 00 216.596 00
Convert SI → English	C	4.925-03
Display U_i	B' R/S " " "	11.076 06 12.434 06 2.859`06 3.279 06 3.899 06

SECTION IV

COMBO 1P: USER INPUT PLY DATA WITH PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 1P: USER INPUT PLY DATA w/PRINTER				
$E_x,...,h_o$	$X,...,F_{xy}^*$	SI→Engl	Engl→SI	

Combo 1P is the final program card used to input, calculate, and store ply properties in their correct memory registers. It should be the Combo selected when the user wishes to input his own ply stiffness and failure data, and has a printing cradle available. Combo 1P is identical to Combo 1 except the results of the calculations made by 1P are automatically printed. The SI to English or English to SI conversions are made exactly as described in the Combo 1 instructions. The Combo 1P program is listed in Appendix D.

Combo 1P can be used by following these steps:

1. Press $\boxed{\text{CLR}}$, read side 1, press $\boxed{\text{CLR}}$, read side 2.

2. Enter E_x, E_y, ν_x, E_s, and h_o as described in Figure 8. These will be labeled "E" and "H" on the printer. The machine calculates and prints automatically:

Q_{xx}, Q_{yy}, Q_{xy}, Q_{ss}. Labeled "Q" by printer.

S_{xx}, S_{yy}, S_{xy}, S_{ss}. Labeled "S" by printer.

U_1, U_2, U_3, U_4, U_5. Labeled "U" by printer.

A_{xx}, A_{yy}, A_{xy}, A_{ss}. Labeled "A" by printer.

a_{xx}, a_{yy}, a_{xy}, a_{ss}. Labeled "AI" by printer.

The definitions of the above quantities are given in the section describing Combo 1.

3. Enter X, X', Y, Y', S, and F_{xy}* as described in Figure 8. These will be labeled "X" and "FXY".

The machine calculates and displays automatically:

F_{xx}, F_{yy}, F_{xy}, F_{ss}, F_x, F_y. Labeled "F" by printer.

G_{xx}, G_{yy}, G_{xy}, G_{ss}, G_x, G_y. Labeled "G" by printer.

The calculator is now ready to accept any lamination Combo.

4. Make SI → English or English → SI changes if desired. The machine will calculate, store, and print a new set of U_i (labeled "U'") and a new h_o (labeled "H'").

5. Transfer results from storage registers (bank 3) onto one side of a card if desired.

Step	Procedure	Press	Display	Printer Label	Printout
1a	Enter E_x	A	4	E	E_x
b	E_y	R/S	3		E_y
c	ν_x	R/S	2		ν_x
d	E_s	R/S	1		E_s
e	h_o	R/S		H	h_o
				Q	Q_{xx}, Q_{yy}, Q_{xy}, Q_{ss}
				S	S_{xx}, S_{yy}, S_{xy}, S_{ss}
				U	U_1, U_2, U_3, U_4, U_5
				A	A_{xx}, A_{yy}, A_{xy}, A_{ss}
				AI	a_{xx}, a_{yy}, a_{xy}, a_{ss}
			1.1		
2a	Enter X	B	5	X	X
b	X'	R/S	4		X'
c	Y	R/S	3		Y
d	Y'	R/S	2		Y'
e	S	R/S	1		S
f	Fxy*	R/S		FXY	F_{xy}*
				F	F_{xx}, F_{yy}, F_{xy}, F_{ss}, F_x, F_y
				G	G_{xx}, G_{yy}, G_{xy}, G_{ss}, G_x, G_y
			1.2		
3	Convert SI → English	C		U'	U_1, U_2, U_3, U_4, U_5 (Engl)
			h_o(Engl)	H'	h_o (Engl)
4	Convert English → SI	D		U'	U_1, U_2, U_3, U_4, U_5 (SI)
			h_o (SI)		h_o (SI)

Figure 8. Combo 1P Instruction Chart

00	15	30 U_1	45 F_{yy}, G_{yy}
01	16 S_{xx}, G_{xx}	31 U_2	46 F_{xy}, G_{xy}
02	17 S_{yy}, G_{yy}	32 U_3	47 F_{ss}, G_{ss}
03	18 S_{xy}, G_{xy}	33 U_4	48 F_x, G_x
04	19 S_{ss}, G_{ss}	34 U_5	49 F_y, G_y
05	20 G_x	35	50
06	21 G_y	36	51
07	22	37	52
08	23 X	38	53
09	24 X'	39	54
10 Q_{xx}	25 E_x, Y	40	55
11 Q_{yy}	26 E_y, Y'	41	56
12 Q_{xy}	27 E_s, S	42	57
13 Q_{ss}	28 ν_x, F_{xy}^*	43	58
14	29	44 F_{xx}, G_{xx}	59 h_o

Figure 9. Combo IP Storage Memories

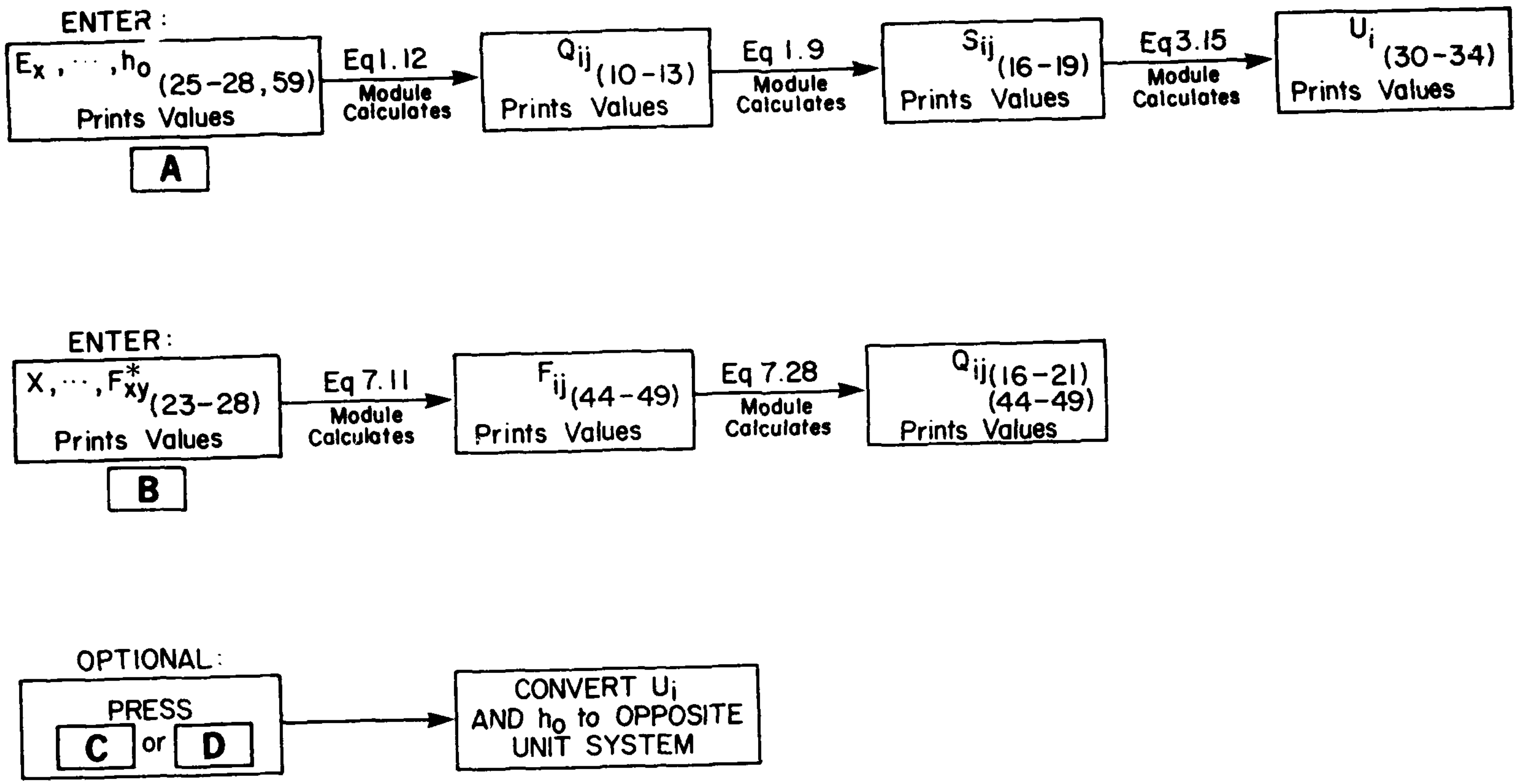


Figure 10. Combo 1P Flow Chart

COMBO 1P SAMPLE PROBLEM: USER INPUT PLY DATA

PROCEDURE	KEY	PRINT
Enter E_x E_y ν_x E_s	A R/S R/S R/S	E 181.000 09 10.300 09 280.000-03 7.170 09
Enter h_o	R/S	H 125.000-06
Print Q_{ij}		Q 181.811 09 10.346 09 2.897 09 7.170 09
Print S_{ij}		S 5.525-12 97.087-12 -1.547-12 139.470-12
Print U_i		U 76.368 09 85.732 09 19.710 09 22.607 09 26.880 09
Print A_{ij}		A 22.726 06 1.293 06 362.116 03 896.250 03
Print a_{ij}		AI 44.199-09 776.699-09 -12.376-09 1.116-06

PROCEDURE	KEY	PRINT
Enter X X' Y Y' S	B R/S R/S R/S R/S	X 1.500 09 1.500 09 40.000 06 246.000 06 68.000 06
Enter F_{xy}*	R/S	FXY -500.000-03
Print F_{ij}		F 444.444-21 101.626-18 -3.360-18 216.263-18 0.000 00 20.935-09
Print G_{ij}		G 12.004 03 10.681 03 -3.069 03 11.118 03 60.647 00 216.596 00
Convert SI → English	C	
Print U_i (English)		U' 11.076 06 12.434 06 2.859 06 3.279 06 3.899 06
Print h_o (English)		H' 4.925-03

T300/5208		B(4)/5505	
SI	ENGLISH	SI	ENGLISH
E	E	E	E
181.000 09	26.251 06	204.000 09	29.587 06
10.300 09	1.494 06	18.500 09	2.683 06
280.000-03	280.000-03	230.000-03	230.000-03
7.170 09	1.040 06	5.590 09	810.732 03
H	H	H	H
125.000-06	4.925-03	125.000-06	4.925-03
Q	Q	Q	Q
181.811 09	26.369 06	204.983 09	29.729 06
10.346 09	1.501 06	18.589 09	2.696 06
2.897 09	420.149 03	4.276 09	620.089 03
7.170 09	1.040 06	5.590 09	810.732 03
S	S	S	S
5.525-12	38.094-09	4.902-12	33.799-09
97.087-12	669.417-09	54.054-12	372.703-09
-1.547-12	-10.666-09	-1.127-12	-7.774-09
139.470-12	961.646-09	178.891-12	1.233-06
U	U	U	U
76.368 09	11.076 06	87.704 09	12.720 06
85.732 09	12.434 06	93.197 09	13.517 06
19.710 09	2.859 06	24.083 09	3.493 06
22.607 09	3.279 06	28.358 09	4.113 06
26.880 09	3.899 06	29.673 09	4.304 06
A	A	A	A
22.726 06	129.865 03	25.62[illegible] 06	146.417 03
1.293 06	7.390 03	2.324 06	13.278 03
362.116 03	2.069 03	534.439 03	3.054 03
896.250 03	5.121 03	698.750 03	3.393 03
AI	AI	AI	AI
44.199-09	7.735-06	39.216-09	6.863-06
776.699-09	135.922-06	432.432-09	75.676-06
-12.576-09	-2.166-06	-9.020-09	-1.578-06
1.116-06	195.258-06	1.431-06	250.447-06
X	X	X	X
1.500 09	217.549 03	1.260 09	18[illegible].741 03
1.500 09	217.549 03	2.500 09	362.582 03
40.000 06	5.801 03	61.000 06	8.847 03
246.000 06	35.678 03	202.000 06	29.297 03
68.000 06	9.862 03	67.000 06	9.717 03
FXY	FXY	FXY	FXY
-500.000-03	-500.000-03	-500.000-03	-500.000-03
F	F	F	F
444.444-21	21.129-12	317.460-21	15.092-12
101.626-18	4.831-09	81.156-18	3.858-09
-3.360-18	-159.753-12	-2.538-18	-120.654-12
216.263-18	10.281-09	222.767-18	10.591-09
0.000 00	0.000 00	393.651-12	2.714-06
20.935-09	144.347-06	11.443-09	78.899-06
G	G	G	G
12.004 03	12.004 03	10.374 03	10.374 03
10.681 03	10.681 03	27.646 03	27.646 03
-3.069 03	-3.069 03	-2.989 03	-2.989 03
11.118 03	11.118 03	6.961 03	6.961 03
60.647 00	60.647 00	129.616 00	129.616 00
216.596 00	216.596 00	214.398 00	214.398 00
U'	U'	U'	U'
11.076 06	76.368 09	12.720 06	87.704 09
12.434 06	85.732 09	13.517 06	93.197 09
2.859 06	19.710 09	3.493 06	24.083 09
3.279 06	22.607 09	4.113 06	28.358 09
3.899 06	26.880 09	4.304 06	29.673 09
H'	H'	H'	H'
4.925-03	125.000-06	4.925-03	125.000-06

	AS/3501 SI	AS/3501 ENGLISH	SCOTCHPLY 1002 SI	SCOTCHPLY 1002 ENGLISH
E	138.000 09	20.015 06	38.600 09	5.598 06
	8.960 09	1.299 06	8.270 09	1.199 06
	300.000-03	300.000-03	260.000-03	260.000-03
	7.100 09	1.030 06	4.140 09	600.435 03
H	125.000-06	4.925-03	125.000-06	4.925-03
Q	138.811 09	20.132 06	39.167 09	5.681 06
	9.013 09	1.307 06	8.392 09	1.217 06
	2.704 09	392.139 03	2.182 09	316.432 03
	7.100 09	1.030 06	4.140 09	600.435 03
S	7.246-12	49.964-09	25.907-12	178.627-09
	111.607-12	769.531-09	120.919-12	833.736-09
	-2.174-12	-14.989-09	-6.736-12	-46.443-09
	140.845-12	971.127-09	241.546-12	1.665-06
U	59.660 09	8.653 06	20.450 09	2.966 06
	64.899 09	9.413 06	15.388 09	2.232 06
	14.252 09	2.067 06	3.329 09	482.872 03
	16.956 09	2.459 06	5.511 09	799.304 03
	21.352 09	3.097 06	7.469 09	1.083 06
A	17.351 06	99.151 03	4.896 06	27.977 03
	1.127 06	6.438 03	1.049 06	5.994 03
	337.975 03	1.931 03	272.725 03	1.558 03
	887.500 03	5.071 03	517.500 03	2.957 03
AI	57.971-09	10.145-06	207.254-09	36.269-06
	892.857-09	156.250-06	967.352-09	169.287-06
	-17.391-09	-3.043-06	-53.886-09	-9.430-06
	1.127-06	197.183-06	1.932-06	338.164-06
X	1.447 09	209.862 03	1.062 09	154.025 03
	1.447 09	209.862 03	610.000 06	88.470 03
	51.700 06	7.498 03	31.000 06	4.496 03
	206.000 06	29.877 03	118.000 06	17.114 03
	93.000 06	13.488 03	72.000 06	10.442 03
FXY	-500.000-03	-500.000-03	-500.000-03	-500.000-03
F	477.598-21	22.706-12	1.544-18	73.386-12
	93.895-18	4.464-09	273.373-18	12.996-09
	-3.348-18	-159.181-12	-10.271-18	-488.303-12
	115.620-18	5.497-09	192.901-18	9.171-09
	0.000 00	0.000 00	-697.725-12	-4.811-06
	14.488-09	99.895-06	23.783-09	163.987-06
G	7.376 03	7.376 03	1.914 03	1.914 03
	7.467 03	7.467 03	18.882 03	18.882 03
	-1.746 03	-1.746 03	1.712 03	1.712 03
	5.828 03	5.828 03	3.306 03	3.306 03
	39.173 00	39.173 00	24.563 00	24.563 00
	130.575 00	130.575 00	198.058 00	198.058 00
U'	8.653 06	59.660 09	2.966 06	20.450 09
	9.413 06	64.899 09	2.232 06	15.388 09
	2.067 06	14.252 09	482.872 03	3.329 09
	2.459 06	16.956 09	799.304 03	5.511 09
	3.097 06	21.352 09	1.083 06	7.469 09
H'	4.925-03	125.000-06	4.925-03	125.000-06

KEVLAR 49/EPOXY		ALUMINUM	
SI	**ENGLISH**	**SI**	**ENGLISH**
E	E	E	E
76.000 09	11.022 06	69.000 09	10.007 06
5.500 09	797.679 03	69.000 09	10.007 06
340.000-03	340.000-03	300.000-03	300.000-03
2.300 09	333.575 03	26.538 09	3.849 06
H	H	H	H
125.000-06	4.925-03	1.000 00	1.000 00
Q	Q	Q	Q
76.641 09	11.115 06	75.824 09	10.997 06
5.546 09	804.409 03	75.824 09	10.997 06
1.886 09	273.499 03	22.747 09	3.299 06
2.300 09	333.575 03	26.538 09	3.849 06
S	S	S	S
13.158-12	90.724-09	14.493-12	99.928-09
181.818-12	1.254-06	14.493-12	99.928-09
-4.474-12	-30.846-09	-4.348-12	-29.978-09
434.783-12	2.998-06	37.681-12	259.812-09
U	U	U	U
32.442 09	4.705 06	75.824 09	10.997 06
35.547 09	5.156 06	0.000 00	0.000 00
8.652 09	1.255 06	40.000-03 ≈0	88.455-03 ≈0
10.538 09	1.528 06	22.747 09	3.299 06
10.952 09	1.588 06	26.538 09	3.849 06
A	A	A	A
9.580 06	54.744 03	75.824 09	10.997 06
693.300 03	3.962 03	75.824 09	10.997 06
235.722 03	1.347 03	22.747 09	3.299 06
287.500 03	1.643 03	26.538 09	3.849 06
AI	AI	AI	AI
105.263-09	18.421-06	14.493-12	99.928-09
1.455-06	254.545-06	14.493-12	99.928-09
-35.789-09	-6.263-06	-4.348-12	-29.978-09
3.478-06	608.696-06	37.681-12	259.812-09
X	X	X	X
1.400 09	203.046 03	400.000 06	58.013 03
235.000 06	34.083 03	400.000 06	58.013 03
12.000 06	1.740 03	400.000 06	58.013 03
53.000 06	7.687 03	400.000 06	58.013 03
34.000 06	4.931 03	230.000 06	33.358 03
FXY	FXY	FXY	FXY
-500.000-03	-500.000-03	-500.000-03	-500.000-03
F	F	F	F
3.040-18	144.502-12	6.250-18	297.131-12
1.572-15	74.750-09	6.250-18	297.131-12
-34.566-18	-1.643-09	-3.125-18	-148.566-12
865.052-18	41.125-09	18.904-18	898.396-12
-2.541-09	-24.415-06	0.000 00	0.000 00
64.465-09	444.489-06	0.000 00	0.000 00
G	G	G	G
13.454 03	13.454 03	28.387 03	28.387 03
47.657 03	47.657 03	28.387 03	28.387 03
2.069 03	2.069 03	1.976 03	1.976 03
4.576 03	4.576 03	13.314 03	13.314 03
-149.822 00	-149.822 00	0.000 00	0.000 00
350.873 00	350.873 00	0.000 00	0.000 00
U'	U'	U'	U'
4.705 06	32.442 09	10.997 06	75.824 09
5.156 06	35.547 09	0.000 00	0.000 00
1.255 06	8.652 09	5.801-06 ≈0	609.897 00 ≈0
1.528 06	10.538 09	3.299 06	22.747 09
1.588 06	10.952 09	3.849 06	26.538 09
H'	H'	H'	H'
4.925-03	125.000-06	39.400 00	25.381-03

SECTION V

COMBO 2: IN-PLANE PROPERTIES WITHOUT PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 2: IN-PLANE PROPERTIES w/o PRINTER				
Core	A_{ij}, a_{ij}	A^*_{ij}, a^*_{ij}	**Unit Ply**	I_ϵ, R_ϵ
$n, \theta_t \rightarrow E^o_i$	$N_i \rightarrow \epsilon_i$	$\theta_t \rightarrow R_t, R'_t$	$\sigma^o_t, \sigma^{o'}_t$	$\epsilon^o_i, \theta_t \rightarrow R_t$

The Combo 2 program will recall the unit ply data stored in bank 3, then drive the composite materials module to calculate the laminate stiffness matrix, compliance matrix, and the apparent elastic constants. For a given loading condition, the program calculates strain components, strain invariants, and strength ratios (allowable stress to applied stress). Failure envelopes in stress and strain space can be plotted using Combo 2. It is to be used when no printer is available. Essentially, Combo 2 accepts the ply stacking sequence and laminate loading as its input. Note that sandwich laminates which contain a core are acceptable. The Combo 2 program is listed in Appendix D.

To use Combo 2:

1. Have U_i, G_{ij}, and h_o for the desired material and in the desired units stored in bank 3.
2. Press [CLR], read side 1, press [CLR], read side 2.
3. No core: Enter n, the total number of plies, then press [A]. Enter θ_1, R/S, θ_2, R/S,...., $\theta_{n/2}$, R/S. The θ_t are entered

with the orientation of the outside ply (top or bottom ply) of the stack first. Further ply orientations are then entered in a sequence working progressively towards the laminate mid-plane. See Figure 11.

Core: Enter n, the total number of plies plus the total number of ply thicknesses that make up core; press $\boxed{A}$. Enter θ_1, R/S, θ_2, R/S,... After entering one angle for each ply orientation (note less than n entries), press A'. See Figures 11 and 12 for details.

The machine calculates:

E_1°, E_2°, ν_{21}°, E_6° — effective in-plane laminate moduli (Equation 4.18)

$$E_1^\circ = \frac{1}{a_{11}h}\ \text{, etc.}$$

A_{11}, A_{22}, A_{12}, A_{66}, A_{16}, A_{26} — in-plane stiffness matrix (Table 4.3, Equation 4.31)

$$\begin{Bmatrix} N_1 \\ N_2 \\ N_6 \end{Bmatrix} = \begin{Bmatrix} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_3 h \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1^\circ \\ \varepsilon_2^\circ \\ \varepsilon_6^\circ \end{Bmatrix}$$

a_{11}, a_{22}, a_{12}, a_{66}, a_{16}, a_{26} — inversion of [A]:

$$\begin{Bmatrix} \varepsilon_1^\circ \\ \varepsilon_2^\circ \\ \varepsilon_6^\circ \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{16} \\ a_{12} & a_{22} & a_{26} \\ a_{16} & a_{26} & a_{66} \end{bmatrix} \begin{Bmatrix} N_1 \\ N_2 \\ N_6 \end{Bmatrix}$$

$$\begin{array}{l|} A^*_{11} \\ A^*_{22} \\ A^*_{12} \\ A^*_{66} \\ A^*_{16} \\ A^*_{26} \end{array}$$

A_{ij}/h:

$$\begin{Bmatrix} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_6 h \end{Bmatrix} = \begin{Bmatrix} N_1 \\ N_2 \\ N_6 \end{Bmatrix} = \begin{bmatrix} & & \\ & A & \\ & & \end{bmatrix} \begin{Bmatrix} \varepsilon_1^\circ \\ \varepsilon_2^\circ \\ \varepsilon_6^\circ \end{Bmatrix} \; ; \; \begin{Bmatrix} \bar{\sigma}_1 \\ \bar{\sigma}_2 \\ \bar{\sigma}_6 \end{Bmatrix} = \begin{bmatrix} & & \\ & A^* & \\ & & \end{bmatrix} \begin{Bmatrix} \varepsilon_1^\circ \\ \varepsilon_2^\circ \\ \varepsilon_6^\circ \end{Bmatrix}$$

$$\begin{array}{l|} a^*_{11} \\ a^*_{22} \\ a^*_{12} \\ a^*_{66} \\ a^*_{16} \\ a^*_{26} \end{array}$$

$a_{ij}h$:

$$\begin{Bmatrix} \varepsilon_1^\circ \\ \varepsilon_2^\circ \\ \varepsilon_6^\circ \end{Bmatrix} = \begin{bmatrix} & & \\ & a & \\ & & \end{bmatrix} \begin{Bmatrix} \bar{\sigma}_1 h \\ \bar{\sigma}_2 h \\ \bar{\sigma}_6 h \end{Bmatrix} \; ; \; \begin{Bmatrix} \varepsilon_1^\circ \\ \varepsilon_2^\circ \\ \varepsilon_6^\circ \end{Bmatrix} = \begin{bmatrix} & & \\ & a^* & \\ & & \end{bmatrix} \begin{Bmatrix} \bar{\sigma}_1 \\ \bar{\sigma}_2 \\ \bar{\sigma}_6 \end{Bmatrix}$$

4. The display will show E_1°. The user has the option of displaying the rest of the engineering constants, A_{ij}, a_{ij}, A^*_{ij}, and/or a^*_{ij}. See Figure 12 for instructions.

5. At this point, the user must input the load. There are two options:

   a. Input selective unit loads to determine failure envelopes and maximum loading allowable.

   b. Input an actual loading case to determine strain invariants and strength ratios.

   Case a deals with the locus of the failure envelope for a selected ply orientation as shown in Figure 14. For a given loading path (N_1:N_2:N_3 ratio remains fixed), it calculates where the path pierces the envelope, i.e., the maximum allowable

stress values along that proportional loading line. By selecting various proportional loading lines, the envelope can be plotted. The data for a sample case is shown in Figure 13 and is plotted in Figure 14. Case b, being an actual loading case, is a point which lies, for allowable loading, somewhere within the envelope.

Case a)

Enter N_1, N_2, N_6 as instructed in Figure 11. To find the values of σ_1° at the piercing point for a given proportional loading (loading line) enter $N_i = 1$, and the other two N's to set the $N_1 : N_2 : N_6$ ratio as desired.

6. Enter θ_t, the orientation of the ply to be examined (See Figure 11).

The machine calculates:

$$\left.\begin{array}{l} R_t \\ R_t' \end{array}\right\} \text{ Not used for Case a.}$$

7. Press D. The machine calculates:

$$\left.\begin{array}{l} \sigma_t^\circ = R_t/h \\ \sigma_t^{\circ\prime} = R_t'/h \end{array}\right| \begin{array}{l} \bar{\sigma}_i \text{ values that pierce failure envelope:} \\ N_i \text{ was set } = 1 = \bar{\sigma}_i h;\ \bar{\sigma}_i = 1/h \end{array}$$

$$R_t = \frac{\bar{\sigma}_i \text{ allowable}}{\bar{\sigma}_i \text{ applied}} = \frac{\bar{\sigma}_i \text{ allowable}}{1/h}$$

$$\bar{\sigma}_i \text{ allowable} = R_t/h = \sigma_t^\circ$$

Recall σ_t°, $\sigma_t^{\circ\prime}$ as desired. The two values of R (and hence two values of σ_t°) arise because the failure criteria is quadratic in R (Equation 7.64), hence R has two roots. Each of these roots corresponds to a point where the loading line intersects the elliptic failure envelope.

Note that the entire envelope for a laminate is a superposition of all

envelopes for every value of θ_t in the laminate. The first ply failure envelope is then the innermost trace of the superpositioned curves. The outer boundary is the ultimate failure envelope.

The failure envelope can also be plotted in strain space. This technique is best illustrated by Figures 12 and 15. For a given ply orientation, the failure envelope is independent of the laminate stacking (independent of A_{ij}). The total laminate failure envelope is again a superposition of individual envelopes.

Case b)

Enter actual N_1, N_2, N_6 as instructed in Figure 11.

The machine calculates:

$$\left.\begin{array}{l} I_\varepsilon = 1/2\ (\varepsilon_1^\circ + \varepsilon_2^\circ) \\ R_\varepsilon = [1/4\ (\varepsilon_1^\circ - \varepsilon_2^\circ)^2 + 1/4\ \varepsilon_6^2]^{1/2} \end{array}\right\} \begin{array}{l} \text{Strain invariants (Equation 2.50)} \\ \text{used to calculate on-axis ply} \\ \text{strains} \end{array}$$

Note ε_1°, ε_2°, ε_6° are stored in locations 23, 24, and 25 and can be recalled if desired.

6. Display I_ε and R_ε if desired (See Figure 12).

7. Enter θ_t, the orientation of the ply to be examined (See Figure 11).

The machine calculates:

$$\left.\begin{array}{l} R_t \\ R_t' \end{array}\right\} \text{strength ratios (Equation 7.48)}$$

$$R = \frac{\bar{\sigma}_i \text{ allowable}}{\bar{\sigma}_i \text{ applied}} = \frac{\varepsilon_i^\circ \text{ allowable}}{\varepsilon_i^\circ \text{ induced}}$$

$$\left.\begin{array}{l} \sigma_t^\circ \\ \sigma_t^{\circ\prime} \end{array}\right\} \text{not used for case b.}$$

8. Recall R_t and R_t' as desired by following the instructions in Figure 11.

The material engineering properties for a *single ply can be* calculated and displayed by pressing D. The A_{ij} (i,j = x,y,s) and a_{ij} can then be recovered by pressing B. Finally, the Q_{ij} and S_{ij} can be displayed by pressing C. The user should exercise caution here, because when C is pressed, the original material data in bank 3 is destroyed. Further lamination calculations cannot be completed until the storage registers are returned to their original condition.

STEP	PROCEDURE	PRESS	DISPLAY
1	Enter ply data		
2a	Enter n	A	n/2
b	Θ_1	R/S	n/2 - 1
c	Θ_2	R/S	n/2 - 2
*	⋮	⋮	⋮
	$\Theta_{n/2-1}$		1
	$\Theta_{n/2}$	R/S,R/S,...	E_1°, E_2°, ν_{21}°, E_6°, 6.1
**			
3a	Enter N_1	B	6.2
b	N_2	R/S	6.6
c	N_6	R/S	60
***			
4	Enter Θ_t	C	R_t
		R/S	R_t'
		R/S	60
5	Display σ_t°,$\sigma_t^{\circ\prime}$	D	σ_t°
		R/S	$\sigma_t^{\circ\prime}$
		R/S	60
****			
6	Unit ply data	D'	E_x
		R/S,R/S,...	E_y,ν_x,E_s

Figure 11. Combo 2 Instruction Chart

STEP	PROCEDURE	PRESS	DISPLAY
*	For sandwich construction		when display = c
		A'	E_1°
		R/S,R/S,...	E_2°, ν_{21}°, E_6°, 6.1
**	Display A_{ij}, a_{ij}	B'	A_{11}
		R/S,R/S,...	A_{22}, A_{12}, A_{66}, A_{16}, A_{26}
			a_{11}, a_{22}, a_{12}, a_{66}, a_{16}, a_{26}
	Display A^*_{ij}, a^*_{ij}	C'	A^*_{11}
		R/S,R/S,...	A^*_{22}, A^*_{12},A^*_{66}, A^*_{16}, A^*_{26}
			a^*_{11}, a^*_{22}, a^*_{12}, a^*_{66}, a^*_{16}, a^*_{26}
***	Calculate strain invariants	E'	I_ε
		R/S	R_ε
		R/S	60
****	Calculate failure envelopes (strain-space)		
	Enter ε_1°	E	8.1
	ε_2°	R/S	8.2
	ε_6°	R/S	60
	Enter Θ	R/S	R
		R/S	R'
		R/S	60

Figure 12. Combo 2 Options

N_1, N_2, N_3 (N/m)	θ_t (deg)	σ_t° (GPa)	$\sigma_t^{\circ\prime}$ (GPa)
1, 0, 0	0 90	.682 .373	1.11 2.27
0, 1, 0	0 90	.373 .682	2.27 1.11
1, 1, 0	0 90	.302 .302	1.96 1.96
-1, 1, 0	0 90	.351 .856	.856 .351
.35, 1, 0	0 90	.356 .512	2.66 1.65
1, .35, 0	0 90	.512 .356	1.65 2.66

Figure 13. Failure Envelope Data in Stress Space for T300/5208 $[0/90]_s$; $N_6 = 0$.

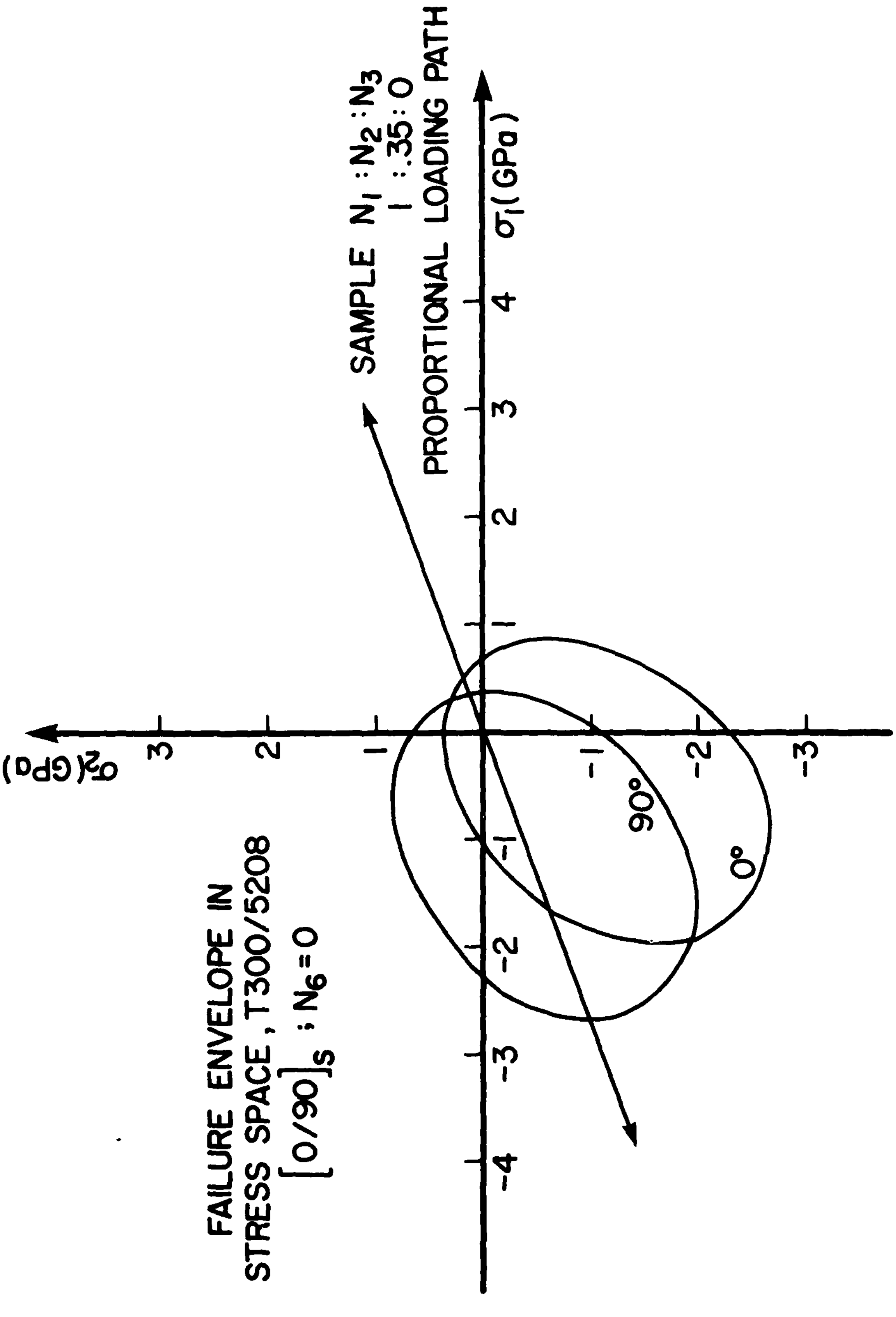

FAILURE ENVELOPE IN
STRESS SPACE, T300/5208
$[0/90]_S$; $N_6=0$
SAMPLE $N_1:N_2:N_3$
1 : .35 : 0
PROPORTIONAL LOADING PATH
σ_1(GPa)
σ_2(GPa)
90°
0°
-4
-3
-2
-1
1
2
3
4
3
2
1
-1
-2
-3

Figure 14

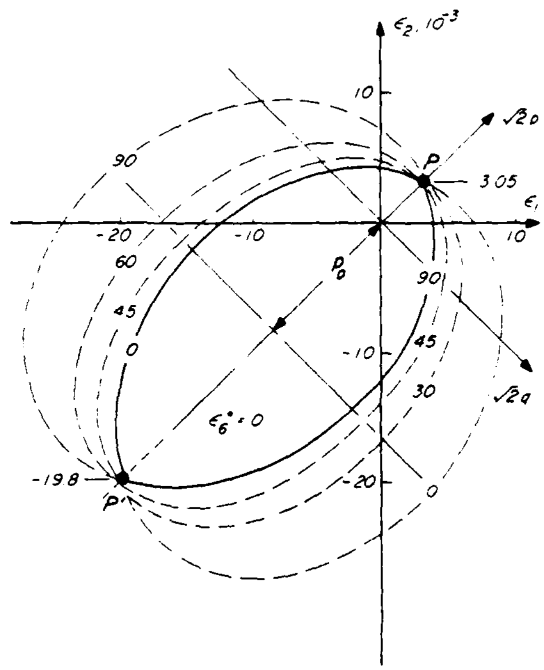
Note: The actual strains at failure for an input unit strain ($\varepsilon_i^\circ = 1$) are the two values of R_t: $\varepsilon^\circ_{i,fail} = R_t \varepsilon^\circ_{i,input}$

$$= R_t,\ R_t'$$

PROCEDURE	KEY	DISPLAY
Enter $\varepsilon_1^\circ = 1$	E	8.1
$\varepsilon_2^\circ = 0$	R/S	8.2
$\varepsilon_6^\circ = 0$	R/S	60
$\theta_t = 0$	R/S	$R_t = 6.94\mathrm{x}10^{-3}$
	R/S	$R_t' = 11.97\mathrm{x}10^{-3}$
	R/S	60
$\theta_t = 45$	R/S	$R_t = 4.74\mathrm{x}10^{-3}$
	R/S	$R_t' = 13.83\mathrm{x}10^{-3}$
	R/S	60
$\theta_t = 90$	R/S	$R_t = 3.88\mathrm{x}10^{-3}$
	R/S	$R_t' = 24.16\mathrm{x}10^{-3}$
	R/S	60

PROCEDURE	KEY	DISPLAY
Enter $\varepsilon_1^\circ = 1$	E	8.1
$\varepsilon_2^\circ = -1$	R/S	8.2
$\varepsilon_6^\circ = 0$	R/S	60
$\theta_t = 0$	R/S	$R_t = 9.19\mathrm{x}10^{-3}$
	R/S	$R_t' = 3.78\mathrm{x}10^{-3}$
	R/S	60
$\theta_t = 45$	R/S	$R_t = 4.74\mathrm{x}10^{-3}$
	R/S	$R_t' = 4.74\mathrm{x}10^{-3}$
	R/S	60
$\theta_t = 90$	R/S	$R_t = 3.78\mathrm{x}10^{-3}$
	R/S	$R_t' = 9.19\mathrm{x}10^{-3}$
	R/S	60

PROCEDURE	KEY	DISPLAY
Enter $\varepsilon_1^\circ = 0$	E	8.1
$\varepsilon_2^\circ = 1$	R/S	8.2
$\varepsilon_6^\circ = 0$	R/S	60
$\theta_t = 0$	R/S	$R_t = 3.88\mathrm{x}10^{-3}$
	R/S	$R_t' = 24.16\mathrm{x}10^{-3}$
	R/S	60
$\theta_t = 45$	R/S	$R_t = 4.74\mathrm{x}10^{-3}$
	R/S	$R_t' = 13.83\mathrm{x}10^{-3}$
	R/S	60
$\theta_t = 90$	R/S	$R_t = 6.94\mathrm{x}10^{-3}$
	R/S	$R_t' = 11.97\mathrm{x}10^{-3}$
	R/S	60



Failure envelopes of T300/5208 off-axis plies in the normal strain space

Figure 15

00	USED	15	A_{26}	30	U_1	45	G_{yy}
01	USED	16	a_{11}, G_{xx}	31	U_2	46	G_{xy}
02	USED	17	a_{22}, G_{yy}	32	U_3	47	G_{ss}
03	USED	18	a_{12}, G_{xy}	33	U_4	48	G_x
04	USED	19	a_{66}, G_{ss}	34	U_5	49	G_y
05	n, n/2	20	a_{16}, G_x	35	θ	50	
06	R_t	21	a_{26}, G_y	36	V_o	51	
07	R'_t	22	$\|A\|$	37	V_1	52	
08	1/h	23	ε_1°	38	V_3	53	p
09	h	24	ε_2°	39	V_2, $\sqrt{\ }$	54	q
10	A_{11}	25	ε_6°	40	V_4	55	r
11	A_{22}	26	N_1, 0	41	θ	56	a
12	A_{12}	27	N_2, 0	42	USED	57	-b/2a
13	A_{66}	28	N_6, 0	43	USED	58	c/a
14	A_{16}	29	USED	44	G_{xx}	59	h_o

Figure 16. Combo 2 Storage Memories

COMBO CARD #2
IN-PLANE STIFFNESS & STRENGTH
(OFF PRINTER)

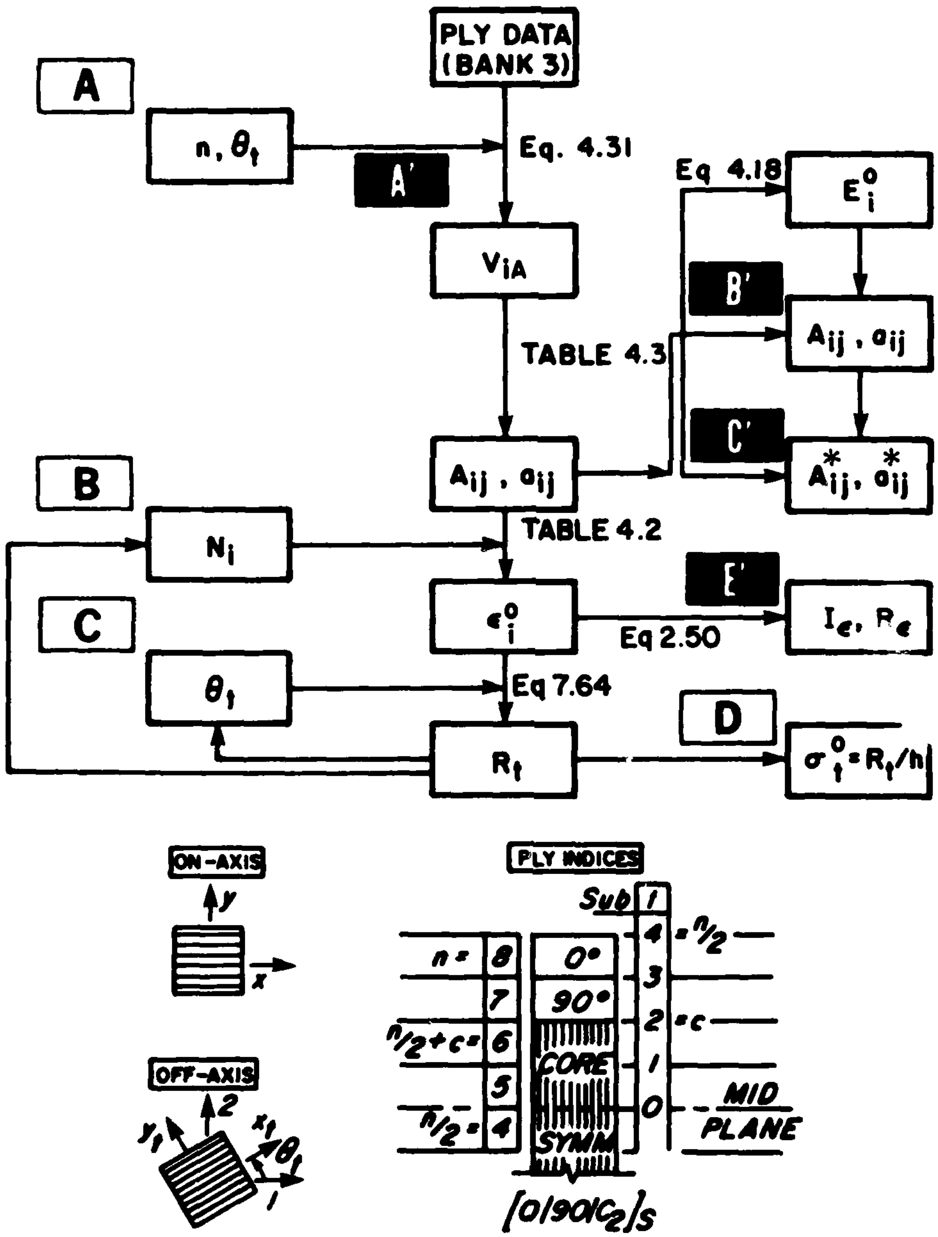


Figure 17. Combo 2 Flow Chart

Combo 2 Sample Problems

The sample problems listed in this section are to aid the user in getting started with the Combo cards/Composite Materials Module. As one works through the sample problems, the user should follow along with the instruction charts, Figures 11 and 12. The sample problems should be followed vertically down the left half of the page, then vertically down the right.

The sample problems with a core denote the core as, say, C_4, meaning the half-core is four times the unit ply thickness, or the total core thickness is eight times the unit ply thickness. A typical real-world core would undoubtedly be much thicker. The user can have a laminate with a core thickness that is not an integer multiple of the unit ply thickness. This would require that n is also not an integer.

All units in the sample problems are as follows:

θ_t	degrees
E_i°	Pa
ν_{21}°	dimensionless
A_{ij}	N/m
a_{ij}	m/N
A_{ij}^*	Pa (N/m^2)
a_{ij}^*	1/Pa (m^2/N)
$I_\varepsilon, R_\varepsilon, R_t, R_t'$	dimensionless
$\sigma_t^\circ, \sigma_t^{\circ\prime}$	Pa

English unit calculations can be completed just as easily. When the material properties in Bank 3 are stored in English units, loads can be entered in lbs/in, etc., provided their dimensions are consistent with the units used to enter the unit ply data.

The six sample problems are discussed below:

#1 and #2 As one would expect, the engineering properties for the $[0_2]_T$ laminate are those of a unit ply. The stiffness and compliance matrices can be retrieved. The order of the engineering properties, stiffness, and compliance components are shown in Figure 18. Next, a unit load in the one direction is applied. The 0° ply is then examined (it is the only orientation available), and the failure stresses are found. Although R_t, the strength ratio, has no meaning for an input unit load, recall $\sigma_t^\circ = R_t/h$, or $R_t = \sigma_t^\circ h$ for the unit load case. But $N_i = \sigma_t^\circ h$, so the failure $N_i = R_t$. This failure N_i is applied to the laminate and, since we are at the failure condition, $R_t = 1$. σ_t° and $\sigma_t^{\circ\prime}$ have no meaning when a non-unit load is applied. The strain invariants can be displayed if desired. For a unit load input, they are meaningless. A unit load is then applied in the 2-direction. Strength in this direction, as one would expect, is much lower.

#3 This example demonstrates that after a given loading has been applied, each θ_t must be examined (0° and 90°, in this case) for its own failure load. The lowest of the failure loads is the first ply failure for the laminate. In this example, the 90° ply fails first for uniaxial loading in the 0° direction.

#4 The $[45/-45]_s$ laminate example shows how much weaker this stacking is than the $[0/90]_s$ laminate, under

uniaxial loading in the 1-direction. If one examined shear carrying abilities, however, the $[45/-45]_s$ would be superior.

#5 Example #5 is a more realistic type of laminate that one would encounter. Because the failure criteria is applied to each ply individually, the failure loads for all plies must be examined.

#6 The laminate in this example is similar to the sample #5 laminate, except that a core has been added to separate the symmetric laminate into halves. The Young's moduli and shear modulus are halved due simply to a doubling of the total laminate thickness. Looking at uniaxial tension effects in the 0° ply, one can see that the load carrying ability, in N/m, is the same as the laminate without the core. The failure stresses are halved due only to the non-load carrying thickness addition of the core. The core for the in-plane loading case shows no advantage over the laminate without the core. The features of a core will be shown later in the flexural loading case.

COMBO 2 SAMPLE PROBLEM #1: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 2	A	1
θ_1 = 0	R/S	E_1° = 181.000 E09
DISPLAY E_i°	R/S	10.300 E09
(optional)	R/S	280.000 E-3
	R/S	7.170 E09
DISPLAY A_{ij} (optional)	B' R/S " " " "	45.453 06 2.587 06 724.231 03 1.792 06 0.000 00 0.000 00
DISPLAY a_{ij} (optional)	R/S " " " " "	22.099-09 388.350-09 -6.188-09 557.880-09 0.000 00 0.000 00
DISPLAY A_{ij}^* (optional)	C' R/S " " " "	181.811 09 10.346 09 2.897 09 7.170 09 0.000 00 0.000 00
DISPLAY a_{ij}^* (optional)	R/S " " " " "	5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00

PROCEDURE	KEY	DISPLAY
ENTER N_1 = 1	B	6.2
N_2 = 0	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 0	C	R_t = 375.000 E03
DISPLAY R_t'	R/S	375.000 E03
σ°	D	1.500 E09
$\sigma^{\circ\prime}$	R/S	1.500 E09
ENTER N_1 = 375. E03	B	6.2
N_2 = 0	R/S	6.6
N_6 = 0	R/S	60
DISPLAY I_ε	E'	2.983 E-3
(optional) R_ε	R/S	5.304 E-3
ENTER θ_t = 0	C	R_t = 1.000 E00
DISPLAY R_t'	R/S	1.000 E00

COMBO 2 SAMPLE PROBLEM #2: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 2	A	1
θ_1 = 0	R/S	E_1° = 181.000 E09
PRINT E_i°	R/S	10.300 E09
(optional)	R/S	280.000 E-3
	R/S	7.170 E09
DISPLAY A_{ij}	B'	45.453 06
(optional)	R/S	2.587 06
	"	724.231 03
	"	1.792 06
	"	0.000 00
	"	0.000 00
	"	
DISPLAY a_{ij}	R/S	22.099-09
(optional)	"	388.350-09
	"	-6.188-09
	"	557.880-09
	"	0.000 00
	"	0.000 00
DISPLAY A_{ij}^*	C'	181.811 09
(optional)	R/S	10.346 09
	"	2.897 09
	"	7.170 09
	"	0.000 00
	"	0.000 00
DISPLAY a_{ij}^*	R/S	5.525-12
(optional)	"	97.087-12
	"	-1.547-12
	"	139.470-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER N_1 = 0	B	6.2
N_2 = 1	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 0	C	R_t = 10.000 E03
DISPLAY R_t'	R/S	61.500 E03
σ°	R/S	40.000 E06
$\sigma^{\circ\prime}$	R/S	246.000 E06
ENTER N_1 = 0	B	6.2
N_2 =		
10.0 E03	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 0	C	R_t = 1.000 E00
DISPLAY R_t'	R/S	6.150 E00

COMBO 2 SAMPLE PROBLEM #3: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0/90]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 4	A	2
$\theta_1 = 0$	R/S	1
$\theta_2 = 90$	R/S	E_1° = 95.991 E09
PRINT E_i°	R/S	95.991 E09
(optional)	R/S	30.152 E-3
	R/S	7.170 E09
DISPLAY A_{ij}	B'	48.039 06
(optional)		48.039 06
	R/S	1.448 06
	"	3.585 06
	"	0.000 00
	"	0.000 00
	"	
DISPLAY a_{ij}	R/S	20.833-09
(optional)	"	20.835-09
	"	-628.215-12
	"	278.940-09
	"	0.000 00
	"	0.000 00
DISPLAY A_{ij}^*	C'	96.079 09
(optional)	R/S	96.079 09
	"	2.897 09
	"	7.170 09
	"	0.000 00
	"	0.000 00
DISPLAY a_{ij}^*	R/S	10.418-12
(optional)	"	10.418-12
	"	-314.108-15
	"	139.470-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER $N_1 = 1$	B	6.2
$N_2 = 0$	R/S	6.6
$N_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	R_t = 340.941 E03
DISPLAY R_t'	R/S	553.853 E03
σ°	D	681.882 E06
$\sigma^{\circ\prime}$	R/S	1.108 E09
ENTER $\theta_t = 90$	C	R_t = 186.698 E03
DISPLAY R_t'	R/S	1.134 E06
σ°	D	373.396 E06
$\sigma^{\circ\prime}$	R/S	2.269 E09

COMBO 2 SAMPLE PROBLEM #4: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[45, -45]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 4	A	2
θ_1 = 45	R/S	1
θ_2 = -45	R/S	E_1° = 25.051 E09
DISPLAY E_i°	R/S	25.051 E09
(optional)	R/S	746.902 E-3
	R/S	46.591 E09
DISPLAY A_{ij} (optional)	B' R/S " " " "	28.329 06 28.329 06 21.159 06 23.295 06 0.000 00 0.000 00
DISPLAY a_{ij} (optional)	R/S " " " " "	79.839-09 79.839-09 -59.632-09 42.927-09 0.000 00 0.000 00
DISPLAY A_{ij}^* (optional)	C' R/S " " " "	56.658 09 56.658 09 42.318 09 46.591 09 0.000 00 0.000 00
DISPLAY a_{ij}^* (optional)	R/S " " " " "	39.919-12 39.919-12 -29.816-12 21.463-12 0.000 00 0.000 00

PROCEDURE	KEY	DISPLAY
ENTER N_1 = 1	B	6.2
N_2 = 0	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 45	C	R_t = 61.614 E03
DISPLAY R_t'	R/S	74.466 E03
σ°	D	123.228 E06
$\sigma^{\circ\prime}$	R/S	148.932 E06
ENTER θ_t = -45	C	R_t = 61.614 E03
DISPLAY R_t'	R/S	74.466 E03
σ°	D	123.228 E06
$\sigma^{\circ\prime}$	R/S	148.932 E06

COMBO 2 SAMPLE PROBLEM #5: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0/90/45/-45]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 8	A	4
$\theta_1 = 0$	R/S	3
$\theta_2 = 90$	"	2
$\theta_3 = 45$	"	1
$\theta_4 = 45$	"	E_1° = 69.676 E09
DISPLAY E_i°	"	69.676 E09
(optional)	"	296.031 E-3
	"	26.880 E09
DISPLAY A_{ij}	B'	76.368 06
(optional)	R/S	76.368 06
	"	22.607 06
	"	26.880 06
	"	0.000 00
	"	0.000 00
DISPLAY a_{ij}	R/S	14.352-09
(optional)	"	14.352-09
	"	-4.249-09
	"	37.202-09
	"	0.000 00
	"	0.000 00
DISPLAY A_{ij}^*	C'	76.368 09
(optional)	R/S	76.368 09
	"	22.607 09
	"	26.880 09
	"	0.000 00
	"	0.000 00
DISPLAY a_{ij}^*	R/S	14.352-12
(optional)	"	14.352-12
	"	-4.249-12
	"	37.202-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER $N_1 = 1$	B	6.2
$N_2 = 0$	R/S	6.6
$N_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	R_t = 581.811 E03
DISPLAY R_t'	R/S	565.417 E03
σ°	D	581.811 E06
$\sigma^{\circ\prime}$	R/S	565.417 E06
ENTER $\theta_t = 90$	C	R_t = 276.119 E03
DISPLAY R_t'	R/S	1.298 E06
σ°	D	276.119 E06
$\sigma^{\circ\prime}$	R/S	1.298 E09
ENTER $\theta_t = 45$	C	R_t = 346.996 E03
DISPLAY R_t'	R/S	675.075 E03
σ°	D	346.996 E06
$\sigma^{\circ\prime}$	R/S	675.075 E06
ENTER $\theta_t = -45$	C	R_t = 346.996 E03
DISPLAY R_t'	R/S	675.075 E03
σ°	D	346.996 E06
$\sigma^{\circ\prime}$	R/S	675.075 E06

COMBO 2 SAMPLE PROBLEM #6: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0/90/45/-45/C_4]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 16	A	8
θ_1 = 0	R/S	7
θ_2 = 90	"	6
θ_3 = 45	"	5
θ_4 = -45	"	4
	A'	E_1° = 34.838 E09
DISPLAY E_i°	R/S	34.838 E09
	"	296.031 E-3
	"	13.440 E09
DISPLAY A_{ij}	B'	76.368 06
(optional)	R/S	76.368 06
	"	22.607 06
	"	26.880 06
	"	0.000 00
	"	0.000 00
DISPLAY a_{ij}	R/S	14.352-09
(optional)	"	14.352-09
	"	-4.249-09
	"	37.202-09
	"	0.000 00
	"	0.000 00
DISPLAY A_{ij}^*	C'	38.184 09
(optional)	R/S	38.184 09
	"	11.304 09
	"	13.440 09
	"	0.000 00
	"	0.000 00
DISPLAY a_{ij}^*	R/S	28.704-12
(optional)	"	28.704-12
	"	-8.497-12
	"	74.404-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER N_1 = 1	B	6.2
N_2 = 0	R/S	6.6
N_6 = 0	R/S	60
ENTER θ_t = 0	C	R_t = 581.811 E03
DISPLAY R_t'	R/S	565.417 E03
σ°	D	290.906 E06
$\sigma^{\circ\prime}$	R/S	282.709 E06
ENTER θ_t = 90	C	R_t = 276.119 E03
DISPLAY R_t'	R/S	1.298 E06
σ°	D	138.060 E06
$\sigma^{\circ\prime}$	R/S	648.792 E06
ENTER θ_t = 45	C	R_t = 346.996 E03
DISPLAY R_t'	R/S	675.075 E03
σ°	R/S	173.498 E06
$\sigma^{\circ\prime}$	R/S	337.538 E06

SECTION VI

COMBO 2P: IN-PLANE STIFFNESS AND STRENGTH OF SYMMETRIC LAMINATES WITH PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 2P: IN-PLANE PROPERTIES w/PRINTER				
Core				
$n, \theta_t \rightarrow E_i^o, A's$	$N_i \rightarrow l_\epsilon, R_\epsilon$	$\theta_t, \rightarrow R_t, \sigma_t^o$		

The Combo 2P program is similar to the Combo 2 program but it can be used with a printer. Because of program memory limitations, Combo 2P cannot be used to directly plot failure envelopes in strain space (strain space plots can be made using E_1^o, E_2^o, ν_{21}, E_6^o, and failure stresses). In stress space, however, it works the same as Combo 2. It also lacks the ability to recover unit ply data which Combo 2 can. The program is listed in Appendix D. Sample problems follow this section.

To use Combo 2P:

1. Have U_i, G_{ij}, and h_o for the desired material and in the desired units stored in bank 3.
2. Press $\boxed{CLR}$, read side 1, press $\boxed{CLR}$, read side 2.
3. No Core: Enter n, the total number of plies, then press $\boxed{A}$. Enter θ_1, R/S, θ_2, R/S,..., $\theta_{n/2}$, R/S. See Figure 18.

   Core: Enter n, the total number of plies plus the total number of ply thicknesses that make up the core; press $\boxed{A}$. Enter θ_1, R/S, θ_2, R/S,... After entering one angle for each ply orientation (note less than n entries), press A. See Figures 18 and 19.

The machine calculates and prints automatically:

E_1°, E_2°, ν_{21}°, E_6° Labeled "E*" by printer

A_{11}, A_{22}, A_{12}, A_{66}, A_{16}, A_{26} Labeled "A" by printer

a_{11}, a_{22}, a_{12}, a_{66}, a_{16}, a_{26} Labeled "AI" by printer

A_{11}^*, A_{22}^*, A_{12}^*, A_{66}^*, A_{16}^*, A_{26}^* Labeled "A*" by printer

a_{11}^*, a_{22}^*, a_{12}^*, a_{66}^*, a_{16}^*, a_{26}^* Labeled "A*I" by printer

The definitions of the above quantities are given in the section describing Combo 2.

4. Enter (as shown in Figure 18) N_1, N_2, N_6 as selected unit loads or an actual loading case. This selection is discussed in detail in the Combo 2 section.

The machine calculates and prints:

I_ε, R_ε Labeled "eI" by printer.

5. Enter θ_t according to Figure 18.

The machine calculates and prints:

R_t, R_t' Labeled "R" by printer

σ_t°, $\sigma_t^{\circ\prime}$ Labeled "Σ" by printer

The definitions of the above quantities are given in the section describing Combo 2.

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
1	Enter ply data				
2a	Enter n	A		n	n/2
b	Θ_1	R/S		Θ_1	n/2 - 1
c	Θ_2	R/S		Θ_2	n/2 - 2
.	.	.		.	.
.	.	.		.	.
.	.	.		.	.
	$\Theta_{n/2-1}$	R/S		$\Theta_{n/2-1}$	1
*	$\Theta_{n/2}$	R/S		SYM	
			E*	E_1°, E_2°, ν_{21}°, E_6°	
			A	A_{11}, A_{22}, A_{12}, A_{66}, A_{16}, A_{26}	
			AI	a_{11}, a_{22}, a_{12}, a_{66}, a_{16}, a_{26}	
			A*	A_{11}^*, A_{22}^*, A_{12}^*, A_{66}^*, A_{16}^*, A_{26}^*	
			A*I	a_{11}^*, a_{22}^*, a_{12}^*, a_{66}^*, a_{16}^*, a_{26}^*	6.1
3a	Enter N_1	B	N	N_1	6.2
b	N_2	R/S		N_2	6.6
c	N_6	R/S		N_6	
			eI	I_ε, R_ε	60
4	Enter Θ_t	C	↑	Θ_t	
			R	R_t, R_t'	
			Σ	σ_t°, $\sigma_t^{\circ\prime}$	60

Figure 18. Combo 2P Instruction Chart

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
*	For sandwich construction			when display = c	
		A'	CR	c	
				SYM	
			E*	printout will continue as previously described in Step 1	6.1

Figure 19. Combo 2P Options

00	USED	15	A_{26}	30	U_1	45	G_{yy}
01	USED	16	a_{11}, G_{xx}	31	U_2	46	G_{xy}
02	USED	17	a_{22}, G_{yy}	32	U_3	47	G_{ss}
03	USED	18	a_{12}, G_{xy}	33	U_4	48	G_x
04	USED	19	a_{66}, G_{ss}	34	U_5	49	G_y
05	n, n/2	20	a_{16}, G_x	35	θ	50	
06	R_t	21	a_{26}, G_y	36	V_o	51	
07	R'_t	22	$\lvert A \rvert$	37	V_1	52	
08	1/h	23	ε_1°	38	V_3	53	p
09	h	24	ε_2°	39	V_2, $\sqrt{\ }$	54	q
10	A_{11}	25	ε_6°	40	V_4	55	r
11	A_{22}	26	N_1, 0	41	θ	56	a
12	A_{12}	27	N_2, 0	42	USED	57	-b/2a
13	A_{66}	28	N_6, 0	43	USED	58	c/a
14	A_{16}	29	USED	44	G_{xx}	59	h_o

Figure 20. Combo 2P Storage Memories

COMBO CARD #2P
IN-PLANE STIFFNESS & STRENGTH
(ON PRINTER)

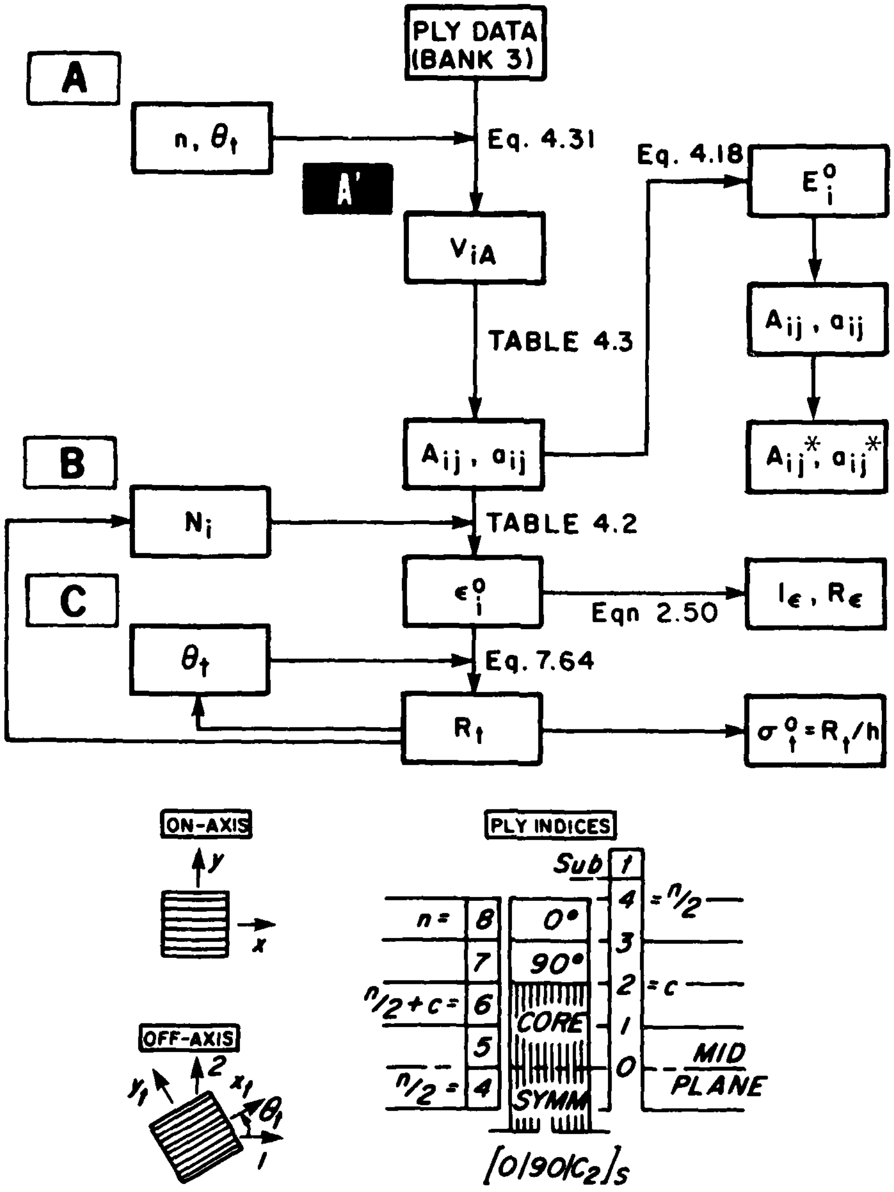


Figure 21. Combo 2P Flow Chart

Combo 2P Sample Problems

The sample problems listed in this section are to aid the user in getting started with the Combo cards/Composite Materials Module. As one works through the sample problems, the user should follow along with the instruction charts, Figures 18 and 19. The sample problems should be followed vertically down the left half of the page, then vertically down the right. Note that the example problems' printer tape extends beyond the blocks describing the printer output. This corresponds to re-entering a new loading condition or examining a different ply orientation. The "looping" done here is best shown in the program diagram, Figure 21.

The sample problems with a core denote the core as, say, C_4, meaning the half-core is four times the unit ply thickness, or the total core thickness is eight times the unit ply thickness. A typical real-world core would undoubtedly be much thicker. The user can have a laminate with a core thickness that is not an integer multiple of the unit ply thickness. This would require that n is also not an integer.

All units in the sample problems are as follows:

θ_t	degrees
E_i°	Pa
ν_{21}°	dimensionless
A_{ij}	N/m
a_{ij}	m/N
A_{ij}^*	Pa (N/m^2)
a_{ij}^*	1/Pa (m^2/N)
$I_\varepsilon, R_\varepsilon, R_t, R_t'$	dimensionless
$\sigma_t^\circ, \sigma_t^{\circ\prime}$	Pa

English unit calculations can be completed just as easily. When the material properties in Bank 3 are stored in English units, loads can be entered in lbs/in, etc., provided their dimensions are consistent with the units used to enter the unit ply data.

The six sample problems are discussed below:

#1 and #2 As one would expect, the engineering properties for the $[0_2]_T$ laminate are those of a unit ply. The stiffness and compliance matrices can be retrieved. The order of the engineering properties, stiffness, and compliance components are shown in Figure 18. Next, a unit load in the one direction is applied. The 0° ply is then examined (it is the only orientation available), and the failure stresses are found. Although R_t, the strength ratio, has no meaning for an input unit load, recall $\sigma_t^\circ = R_t/h$, or $R_t = \sigma_t^\circ h$ for the unit load case. But $N_i = \sigma_t^\circ h$, so the failure $N_i = R_t$. This failure N_i is applied to the laminate and, since we are at the failure condition, $R_t = 1$. σ_t° and $\sigma_t^{\circ\prime}$ have no meaning when a non-unit load is applied. The strain invariants can be displayed if desired. For a unit load input, they are meaningless. A unit load is then applied in the 2-direction. Strength in this direction, as one would expect, is much lower.

#3 This example demonstrates that after a given loading has been applied, each θ_t must be examined (0° and 90°, in this case) for its own failure load. The lowest of the failure loads is the first ply failure for the

laminate. In this example, the 90° ply fails first for uniaxial loading in the 0° direction.

#4 The $[45/-45]_S$ laminate example shows how much weaker this stacking is than the $[0/90]_S$ laminate, under uniaxial loading in the 1-direction. If one examined shear carrying abilities, however, the $[45/-45]_S$ would be superior.

#5 Example #5 is a more realistic type of laminate that one would encounter. Because the failure criteria is applied to each ply individually, the failure loads for all plies must be examined. The -45° ply should also have been examined, but space did not allow this.

#6 The laminate in this example is similar to the sample #5 laminate, except that a core has been added to separate the symmetric laminate into halves. The Young's moduli and shear modulus are halved due simply to a doubling of the total laminate thickness. Looking at uniaxial tension effects in the 0° ply, one can see that the load carrying ability, in N/m, is the same as the laminate without the core. The failure stresses are halved due only to the non-load carrying thickness addition of the core. The core for the in-plane loading case shows no advantage over the laminate without the core. The features of a core will be shown later in the flexural loading case.

COMBO 2P SAMPLE PROBLEM #1: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
			ENTER N_1 N_2 N_6	B R/S R/S	N 1.000 00 0.000 00 0.000 00
ENTER n ENTER σ_1	A R/S	2.000 00 0.000 00 SYM	PRINT I_ε R_ε		eI 7.956-09 14.144-09
			ENTER Θ_t	C	T 0.000 00
PRINT E_i°		E+ 181.000 09 10.300 09 290.000-03 7.170 09	PRINT R_t R_t'		R 375.000 03 375.000 03
PRINT A_{ij}		A 45.453 06 2.587 06 724.231 03 1.792 06 0.000 00 [illegible]	PRINT σ° $\sigma^{\circ\prime}$		Σ 1.500 09 1.500 09
					N 375.000 03 0.000 00 0.000 00
PRINT a_{ij}		A I 22.095-09 388.350-09 -6.186-09 557.880-09 0.000 00 0.000 00			eI 2.983-03 5.304-03
					T 0.000 00
PRINT A_{ij}^*		A* 181.811 09 10.346 09 3.397 09 7.170 09 0.000 00 0.000 00			R 1.000 00 1.000 00
					Σ 4.000 03 4.000 03
PRINT a_{ij}^*		A*I 5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00			

COMBO 2P SAMPLE PROBLEM #2: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	2.000 00
ENTER θ_1	R/S	0.000 00 SYM
PRINT E_i°		E* 181.000 09 10.300 09 280.000-03 7.170 09
PRINT A_{ij}		A 45.453 06 2.587 06 724.231 03 1.792 06 0.000 00 0.000 00
PRINT a_{ij}		AI 22.099-09 388.350-09 -6.189-09 557.880-09 0.000 00 0.000 00
PRINT A_{ij}^*		A* 181.811 09 10.346 09 2.897 09 7.170 09 0.000 00 0.000 00
PRINT a_{ij}^*		A*I 5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER N_1 N_2 N_6	B R/S R/S	N 0.000 00 1.000 00 0.000 00
PRINT I_ε R_ε		eI 191.081-09 197.269-09
ENTER Θ_t	C	t 0.000 00
PRINT R_t R_t'		R 10.000 03 61.500 03
PRINT σ° $\sigma^{\circ\prime}$		Σ 40.000 06 246.000 06
		N 0.000 00 10.000 03 0.000 00
		eI 1.911-03 1.973-03
		t 0.000 00
		R 1.000 00 6.150 00
		Σ 4.000 03 24.600 03

COMBO 2P SAMPLE PROBLEM #3: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0/90]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	4. 00
ENTER θ_1 θ_2	R/S R/S	0.000 00 90.000 00 SYM
PRINT E_i°		E* 95.991 09 95.991 09 30.152-03 7.170 09
PRINT A_{ij}		A 48.039 06 48.039 06 1.448 06 3.585 06 0.000 00 0.000 00
PRINT a_{ij}		AI 20.835-09 20.835-09 -628.215-12 278.940-09 0.000 00 0.000 00
PRINT A_{ij}^*		A* 96.079 09 96.079 09 2.897 09 7.170 09 0.000 00 0.000 00
PRINT a_{ij}^*		A*I 10.418-12 10.418-12 -314.108-15 139.470-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER N_1 N_2 N_6	B R/S R/S	N 1.000 00 0.000 00 0.000 00
PRINT I_ε R_ε		εI 10.104-09 10.732-09
ENTER Θ_t	C	↑ 0.000 00
PRINT R_t R_t'		R 340.941 03 553.853 03
PRINT σ° $\sigma^{\circ\prime}$		Σ 681.882 06 1.108 09
		↑ 90.000 00
		R 186.698 03 1.134 06
		Σ 373.396 06 2.269 09

COMBO 2P SAMPLE PROBLEM #4: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[45/-45]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	4.000 00
ENTER θ_1 θ_2	R/S R/S	45.000 00 -45.000 00 SYM
PRINT E_i°		E* 25.051 09 25.051 09 746.902-03 46.591 09
PRINT A_{ij}		A 28.329 06 28.329 06 21.159 06 23.295 06 0.000 00 0.000 00
PRINT a_{ij}		AI 79.839-09 79.839-09 -59.632-09 42.927-09 0.000 00 0.000 00
PRINT A_{ij}^*		A* 56.658 09 56.658 09 42.318 09 46.591 09 0.000 00 0.000 00
PRINT a_{ij}^*		A*I 39.919-12 39.919-12 -29.816-12 21.463-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER N_1 N_2 N_6	B R/S R/S	N 1.000 00 0.000 00 0.000 00
PRINT I_ε R_ε		eI 10.104-09 69.735-09
ENTER Θ_t	C	† 45.000 00
PRINT R_t R'_t		R 61.614 03 74.466 03
PRINT σ° $\sigma^{\circ\prime}$		Σ 123.228 06 148.932 06
		† -45.000 00 R 61.614 03 74.466 03 Σ 123.228 06 148.932 06

COMBO 2P SAMPLE PROBLEM #5: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: $[0/90/45/-45]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT	PROCEDURE	KEY	PRINT
ENTER n	A	8. 00	ENTER N_1 N_2 N_6	B R/S R/S	N 1.000 00 0.000 00 0.000 00
ENTER θ_1 θ_2 θ_3 θ_4	R/S R/S R/S R/S	0.000 00 90.000 00 45.000 00 -45.000 00 SYM	PRINT I_ε R_ε		eI 5.052-09 9.300-09
PRINT E_i°		E* 69.676 09 69.676 09 296.031-03 26.880 09	ENTER Θ_t	C	↑ 0.000 00
PRINT A_{ij}		A 76.368 06 76.368 06 22.607 06 26.880 06 0.000 00 0.000 00	PRINT R_t R_t'		R 581.811 03 565.417 03
PRINT a_{ij}		AI 14.352-09 14.352-09 -4.249-09 37.202-09 0.000 00 0.000 00	PRINT σ° $\sigma^{\circ\prime}$		Σ 581.811 06 565.417 06
PRINT A_{ij}^*		A* 76.368 09 76.368 09 22.607 09 26.880 09 0.000 00 0.000 00			↑ 90.000 00 R 276.119 03 1.298 06 Σ 276.119 06 1.298 09
PRINT a_{ij}^*		A*I 14.352-12 14.352-12 -4.249-12 37.202-12 0.000 00 0.000 00			↑ 45.000 00 R 346.996 03 675.075 03 Σ 346.996 06 675.075 06

COMBO 2P SAMPLE PROBLEM #6: IN-PLANE STIFFNESS AND STRENGTH

LAMINATE: [0/90/45/-45/C_4] MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	16.000 00
ENTER θ_1 θ_2 θ_3 θ_4 	R/S R/S R/S R/S A'	0.000 00 90.000 00 45.000 00 -45.000 00 CR 4.000 00 SYM
PRINT E_i°		E* 34.838 09 34.838 09 296.031-03 13.440 09
PRINT A_{ij}		A 76.368 06 76.368 06 22.607 06 26.880 06 0.000 00 0.000 00
PRINT a_{ij}		AI 14.352-09 14.352-09 -4.249-09 37.202-09 0.000 00 0.000 00
PRINT A_{ij}^*		A* 38.184 09 38.184 09 11.304 09 13.440 09 0.000 00 0.000 00
PRINT a_{ij}^*		A*I 28.704-12 28.704-12 -8.497-12 74.404-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER N_1 N_2 N_6	B R/S R/S	N 1.000 00 0.000 00 0.000 00
PRINT I_ε R_ε		eI 5.052-09 9.300-09
ENTER Θ_t	C	† 0.000 00
PRINT R_t R_t'		R 581.811 03 565.417 03
PRINT σ° $\sigma^{\circ\prime}$		Σ 290.906 06 282.709 06
		† 90.000 00
		R 276.119 03 1.298 06
		Σ 138.060 06 648.792 06
		† 45.000 00
		R 346.996 03 675.075 03
		Σ 173.498 06 337.538 06

SECTION VII

COMBO 3: FLEXURAL PROPERTIES WITHOUT PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 3: FLEXURAL PROPERTIES w/o PRINTER				
Core	D_{ij}, d_{ij}	D^*_{ij}, d^*_{ij}		
$n, \theta_t \rightarrow E_i^f$	$M_i \rightarrow k_i$	$\theta_t, t \rightarrow R_t, R'_t$	$\sigma_t{}^f, \sigma_t{}^{f'}$	

Combo 3 is a program which takes the ply properties from the storage memories and calculates laminate flexural properties. These include apparent elastic constants, flexural stiffness and compliance matrices, strength ratios, and allowable bending moments. It can be used to quickly plot failure envelopes in moment-space. This combo should be used when no printer is available. Appendix D contains a listing of the entire program.

To use Combo 3:

1. Have U_i, G_{ij}, and h_0 for the desired material and in the desired units stored in bank 3.
2. Press [CLR], read side 1, press [CLR], read side 2.
3. No core: Enter n, the total number of plies, then press [A]. Enter θ_1, R/S,..., $\theta_{n/2}$, R/S. The θ_t are entered with the orientation of the outermost ply of the stack first. Further θ_t are entered in order as t approaches the laminate mid-plane.

Core: Enter n, the total number of plies plus the total number of ply thicknesses that make up the core; press $\boxed{A}$. Enter θ_1 R/S, θ_2, R/S,... After entering one angle for each ply orientation (note less than n entries), press A. See Figures 22 and 23 for details.

The machine calculates:

E_1^f, E_2^f, ν_{21}^f, E_6^f — effective flexural laminate moduli (Equations 5.21, 5.22, 5.23)

$$E_1^f = \frac{12}{h^3 d_{11}}, \text{ etc.}$$

D_{11}, D_{22}, D_{12}, D_{66}, D_{16}, D_{26} — flexural stiffness matrix (Table 5.3, Equation 5.40)

$$\begin{Bmatrix} M_1 \\ M_2 \\ M_6 \end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} k_1 \\ k_2 \\ k_6 \end{Bmatrix}$$

where $\varepsilon_1^f(z) = zk_1$

$\varepsilon_2^f(z) = zk_2$

$\varepsilon_6^f(z) = zk_6$

d_{11}, d_{22}, d_{12}, d_{66}, d_{16}, d_{26} — inversion of [D]:

$$\begin{Bmatrix} k_1 \\ k_2 \\ k_6 \end{Bmatrix} = \begin{bmatrix} d_{11} & d_{12} & d_{16} \\ d_{12} & d_{22} & d_{26} \\ d_{16} & d_{26} & d_{66} \end{bmatrix} \begin{Bmatrix} M_1 \\ M_2 \\ M_6 \end{Bmatrix}$$

$$\begin{array}{l} D^*_{11} \\ D^*_{22} \\ D^*_{12} \\ D^*_{66} \\ D^*_{16} \\ D^*_{26} \end{array} \left[\begin{array}{l} D_{ij}/h^*; h^* = (1 - z_c)^3 h^3/12 \text{ (Equations 5.30, 5.49):} \\ \begin{Bmatrix} \sigma_1^f \\ \sigma_2^f \\ \sigma_6^f \end{Bmatrix} = \begin{bmatrix} & & \\ & D^* & \\ & & \end{bmatrix} \begin{Bmatrix} \varepsilon_1^f \\ \varepsilon_2^f \\ \varepsilon_6^f \end{Bmatrix} \end{array} \right.$$

note: σ_i^f and ε_i^f are defined in Appendix A.

$$\begin{array}{l} d^*_{11} \\ d^*_{22} \\ d^*_{12} \\ d^*_{66} \\ d^*_{16} \\ d^*_{26} \end{array} \left[\begin{array}{l} d_{ij}\, h^*: \\ \begin{Bmatrix} \varepsilon_1^f \\ \varepsilon_2^f \\ \varepsilon_6^f \end{Bmatrix} = \begin{bmatrix} & & \\ & d^* & \\ & & \end{bmatrix} \begin{Bmatrix} \sigma_1^f \\ \sigma_2^f \\ \sigma_6^f \end{Bmatrix} \end{array} \right.$$

4. The display will show E_1^f. The user has the option of displaying the rest of the engineering constants, D_{ij}, d_{ij}, D^*_{ij}, and/or d^*_{ij}. See Figures 22 and 23 for instructions.
5. At this point, the user must input the load. There are two options:

   a) Input selective unit loads to determine failure envelopes and maximum loading allowable.

   b) Input an actual loading case to determine strength ratios.

   Case a deals with the locus of the failure envelope for a selected ply in the laminate. For a given loading path (constant $M_1 = M_2 = M_6$), it calculates where the path pierces the envelope, i.e., the maximum allowable σ_t^f values along that proportional loading line. Using a technique similar to the

one detailed in the Combo 2 explanation, failure envelopes can be plotted. Case b, an actual input loading case, is a point which lies, for an allowable loading, somewhere within the envelope.

Case a)

Enter M_1, M_2, M_6 as instructed in Figure 22. To find the values of σ_i^f which pierce the failure envelope (for a given proportional loading), enter $M_i = 1$, and the other two M's to set the $M_1 : M_2 : M_6$ ratio as desired.

6. Enter ϑ_t and t, the orientation and the ply number of the ply to be examined (see Figure 22).

The machine calculates:

$\left.\begin{matrix} R_t \\ R_t' \end{matrix}\right\}$ not used for case a.

7. Press D. The machine calculates:

$\left.\begin{matrix} \sigma_i^f \\ \sigma_i^{f'} \end{matrix}\right\}$ Values of σ_i^f (σ_i^f is defined in Appendix A), when $N_i = 1$, which pierce the failure envelope:

$$M_i = 1 = \int \sigma_i z dz = \frac{h^2}{6} \sigma_i^f \; ; \; \sigma_i^f = \frac{6}{h^2}$$

$$\sigma^f_{i,allow} = R_t \sigma^f_{i,appl} = \frac{6}{h^2} R_t$$

If the applied moment at failure is desired:

$$M_{i,allow} = \frac{h^2}{6} \sigma^f_{i,allow}$$

To find failure envelopes or simply check failure points for the entire laminate, it is not necessary to make one run for each of the plies. Instead, make one run for each ply angle (θ_t) and

choose t to be the outermost ply with that orientation, since it experiences the highest stress.

Case b)

Enter actual M_1, M_2, M_6 as instructed in Figure 22.

The machine calculates:

k_1, k_2, and k_6, which are then stored in locations 23, 24, and 25. They can be recalled if desired.

6. Enter θ_t and t, the orientation and the number of the ply to be examined (see Figure 22).

The machine calculates:

$$\left.\begin{array}{l} R_t \\ R'_t \end{array}\right\} \text{strength ratios:}$$

$$M_{i,\text{allowable}} = R_t \, M_{i,\text{applied}}$$

$$\sigma^f_{i,\text{allowable}} = R_t \, \sigma^f_{i,\text{applied}}$$

7. Recall R_t and R'_t as desired by following the instructions in Figure 22.

Again, as in case a, it is not necessary to examine the failure moments for every ply in the laminate. Simply calculate strength ratios for one ply per orientation angle. The ply selected for a given orientation should be the outermost ply with that orientation, since it receives greater bending stress than the more interior plies.

STEP	PROCEDURE	PRESS	DISPLAY
1	Enter ply data		
2a	Enter n	A	n/2
b	Θ_1	R/S	n/2 - 1
c	Θ_2	R/S	n/2 - 2
	. . .	. . .	. . .
*	$\Theta_{n/2 - 1}$		1
	$\Theta_{n/2}$	R/S, R/S,...	E_1^f, E_2^f, ν_{21}^f, E_6^f, 6.1
**			
3a	Enter M_1	B	6.2
b	M_2	R/S	6.6
c	M_6	R/S	60
4a	Enter Θ_t	C	37
b	t	R/S	R_t
		R/S	R_t'
		R/S	60
5	Display σ^f, $\sigma^{f'}$	D	σ_t^f
		R/S	$\sigma_t^{f'}$
		R/S	60

Figure 22. Combo 3 Instruction Chart

STEP	PROCEDURE	PRESS	DISPLAY
*	For sandwich construction		when display = c
		A'	E_1^f
		R/S, R/S,...	E_2^f, ν_{21}^f, E_6^f, 6.1
**	Display D_{ij}, d_{ij}	B'	D_{11}
		R/S, R/S,...	D_{22}, D_{12}, D_{66}, D_{16}, D_{26}
			d_{11}, d_{22}, d_{12}, d_{66}, d_{16}, d_{26}, 6.1
	Display D_{ij}^*, d_{ij}^*	C'	D_{11}^*
			D_{22}^*, D_{12}^*, D_{66}^*, D_{16}^*, D_{26}^*
		R/S, R/S,...	d_{11}^*, d_{22}^*, d_{12}^*, d_{66}^*, d_{16}^*, d_{26}^*, 6.1

Figure 23. Combo 3 Options

00	USED	15	D_{26}	30	U_1	45	G_{yy}
01	USED	16	d_{11}, G_{xx}	31	U_2	46	G_{xy}
02	USED	17	d_{22}, G_{yy}	32	U_3	47	G_{ss}
03	USED	18	d_{12}, G_{xy}	33	U_4	48	G_x
04	USED	19	d_{66}, G_{ss}	34	U_5	49	G_y
05	n, n/2, t	20	d_{16}, G_x	35	θ	50	
06	R_t	21	d_{26}, G_y	36	V_o	51	
07	R'_t	22	$\lvert D \rvert$	37	V_1	52	
08	$12/h^3$	23	k_1, ε_1	38	V_3	53	p
09	h	24	k_2, ε_2	39	V_2, $\sqrt{}$	54	q
10	D_{11}	25	k_6, ε_6	40	V_4	55	r
11	D_{22}	26	M_1, 0	41	θ	56	a
12	D_{12}	27	M_2, 0	42	USED	57	-b/2a
13	D_{66}	28	M_6, 0	43	USED	58	c/a
14	D_{16}	29	USED	44	G_{xx}	59	h_o

Figure 24. Combo 3 Storage Memories

COMBO CARD #3
FLEXURAL STIFFNESS & STRENGTH
(OFF PRINTER)

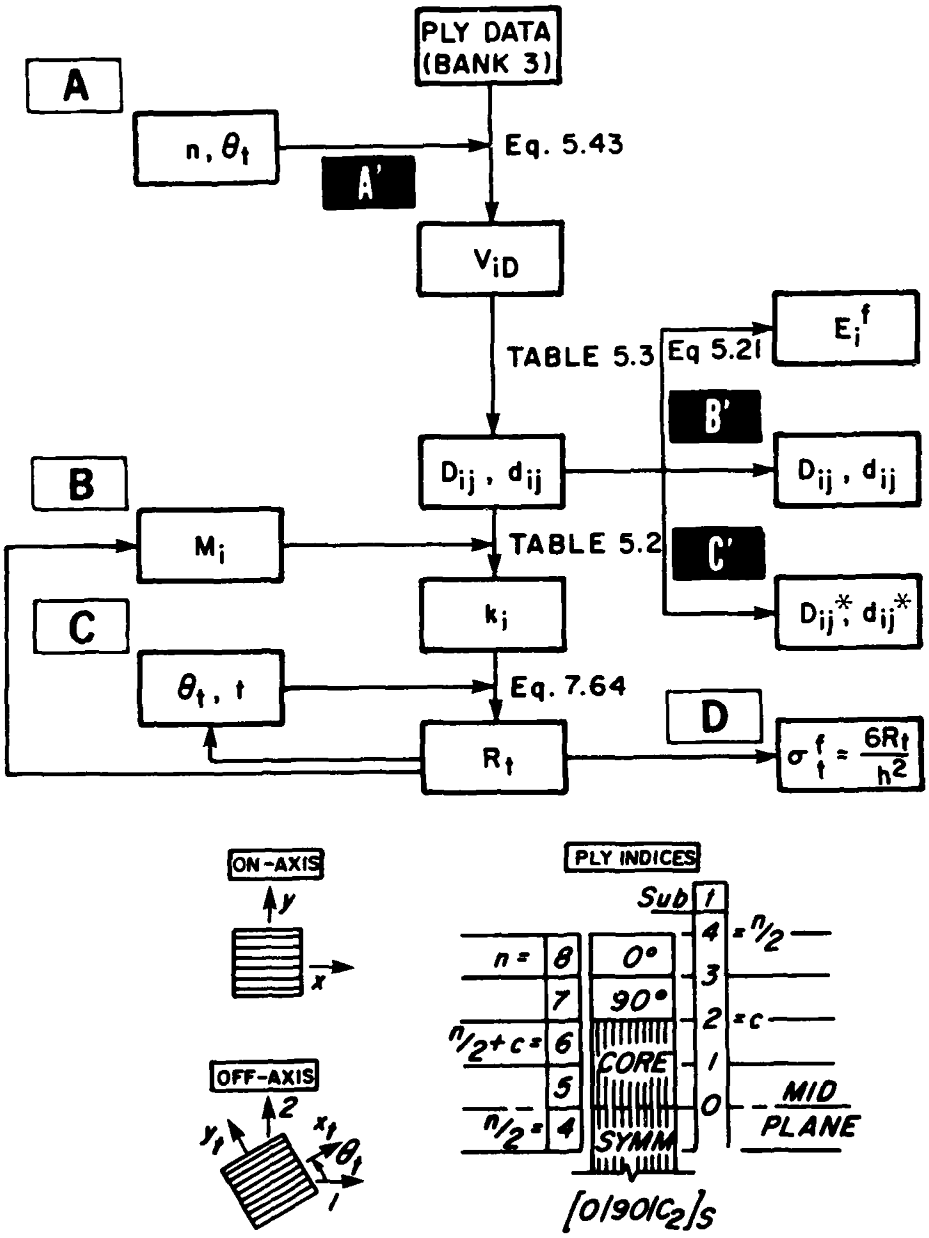


Figure 25. Combo 3 Flow Chart

Combo 3 Sample Problems

As in the Combo 2 section, one should follow the instruction charts, Figures 22 and 23, when working through the sample problems. The sample problems should be followed vertically down the left half of the page, then the right.

The entry of sample problems with a core is exactly the same as that described in Combo 2 and 2P. Again, a core that is a non-integer multiple of unit ply thickness is permissable. Problem #3 demonstrates this.

Additional units for this Combo are, in the case of the sample problems listed:

D_{ij}	N-m
d_{ij}	1/N-m
D^*_{ij}	N/m^2 (Pa)
d^*_{ij}	m^2/N (1/Pa)

English unit calculations can be completed just as easily. When the material properties in Bank 3 are stored in English units, loads can be entered in in-lbs/in, etc., proveded their dimensions are consistent with the units used to enter the unit ply data.

The six sample problems are discussed below:

#1 The failure σ_t^f is calculated, then the failure moment $= h^2/6\ \sigma_t^f$ is applied to show $R_t = 1$ can be recovered.

#2 This laminate is the same as the one in example #1, except the plies have been separated by a core. Note that for the same ply weight, the maximum moment allowable increases 250% from the original laminate.

#3 Increasing the core thickness further increases the

maximum allowable bending moment. This example also demonstrates how to enter a core thickness that is not an integer multiple of unit ply thickness.

#4, #5, #6 This example shows that for the quasi-isotropic lay-up under bending w.r.t. the 1-axis only, the 90° ply fails first. By halving the ply weight and adding a core, 57.8% of the strength is recovered. Or, by taking the original #4 laminate and doubling its thickness with a core, its bending strength is 235% of what it was originally. The bending strength increase due to a lightweight core is obvious.

COMBO 3 SAMPLE PROBLEM #1: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 2	A	1
$\theta_1 = 0$	R/S	E_1^f = 181.000 E09
DISPLAY E_i^f	R/S	10.300 E09
	R/S	280.000 E-3
	R/S	7.170 E09
DISPLAY D_{ij} (optional)	B'	236.7[illegible]-03
	R/S	13.472-03
	"	3.772-03
	"	9.336-03
	"	0.000 00
	"	0.000 00
DISPLAY d_{ij} (optional)	R/S	4.243 00
	"	74.563 00
	"	-1.188 00
	"	107.113 00
	"	0.000 00
	"	0.000 00
DISPLAY D^*_{ij} (optional)	C'	181.811 09
	R/S	10.346 09
	"	2.897 09
	"	7.170 09
	"	0.000 00
	"	0.000 00
DISPLAY d^*_{ij} (optional)	R/S	5.525-12
	"	97.087-12
	"	-1.547-12
	"	139.470-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER $M_1 = 1$	B	6.2
$M_2 = 0$	R/S	6.6
$M_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	37
t = 1	R/S	R_t = 15.625 E00
DISPLAY R_t'	R/S	15.625 E00
σ^f	D	1.500 E09
$\sigma^{f'}$	R/S	1.500 E09
ENTER M_1 = 15.625 E00	B	6.2
$M_2 = 0$	R/S	6.6
$M_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	37
t = 1	R/S	R_t = 1.000 E00
DISPLAY R_t'	R/S	1.000 E00

COMBO 3 SAMPLE PROBLEM #2: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/C]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n =4	A	2
θ_1 = 0	R/S	1
	A'	E_1^f = 158.375 E09
DISPLAY E_i^f	R/S	9.012 E09
(optional)	R/S	280.000 E-3
	R/S	6.274 E09
DISPLAY D_{ij}	B'	1.657 00
(optional)	R/S	94.301-03
	"	26.404-03
	"	65.352-03
	"	0.000 00
	"	0.000 00
DISPLAY d_{ij}	R/S	606.156-03
(optional)	"	10.652 00
	"	-169.724-03
	"	15.302 00
	"	0.000 00
	"	0.000 00
DISPLAY D^*_{ij}	C'	159.085 09
(optional)	R/S	9.053 09
	"	2.535 09
	"	6.274 09
	"	0.000 00
	"	0.000 00
DISPLAY d^*_{ij}	R/S	6.314-12
(optional)	"	110.957-12
	"	-1.768-12
	"	159.394-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER M_1 = 1	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 2	R/S	R_t = 54.688 E00
DISPLAY R_t'	R/S	54.688 E00
σ^f	D	1.313 E09
$\sigma^{f'}$	R/S	1.313 E09
ENTER M_1 =		
54.688 E00	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 2	R/S	R_t = 999.991 E-3
DISPLAY R_t'	R/S	999.991 E-3

COMBO 3 SAMPLE PROBLEM #3: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/C_{1,3}]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 4.6	A	2.3
$\theta_1 = 0$	R/S	1.3
	A'	E_1^f = 148.317 E09
DISPLAY E_i^f	R/S	8.440 E09
(optional)	R/S	280.000 E-3
	R/S	5.875 E09
DISPLAY D_{ij} (optional)	B'	2.360 00
	R/S	134.311-03
	"	37.607-03
	"	93.079-03
	"	0.000 00
	"	0.000 00
DISPLAY d_{ij} (optional)	R/S	425.586-03
	"	7.479 00
	"	-119.164-03
	"	10.744 00
	"	0.000 00
	"	0.000 00
DISPLAY D^*_{ij} (optional)	C'	148.981 09
	R/S	8.478 09
	"	2.374 09
	"	5.875 09
	"	0.000 00
	"	0.000 00
DISPLAY d^*_{ij} (optional)	R/S	6.742-12
	"	118.482-12
	"	-1.888-12
	"	170.204-12
	"	0.000 00
	"	0.000 00

PROCEDURE	KEY	DISPLAY
ENTER $M_1 = 1$	B	6.2
$M_2 = 0$	R/S	6.6
$M_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	37
t = 2.3	R/S	R_t = 67.731 E00
DISPLAY R_t'	R/S	67.731 E00
σ^f	D	1.229 E09
$\sigma^{f'}$	R/S	1.229 E09
ENTER M_1 = 67.73 E00	B	6.2
$M_2 = 0$	R/S	6.6
$M_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	37
t = 2.3	R/S	R_t = 1.000 E00
DISPLAY R_t'	R/S	1.000 E00

COMBO 3 SAMPLE PROBLEM #4: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/90/45/-45/C_4]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY	PROCEDURE	KEY	DISPLAY
			ENTER M_1 = 1	B	6.2
			M_2 = 0	R/S	6.6
			M_6 = 0	R/S	60
ENTER n = 16	A	8	ENTER θ_t = 0	C	37
θ_1 = 0	R/S	7	t = 8	R/S	R_t = 404.279 E00
θ_2 = 90	R/S	6	DISPLAY R_t'	R/S	456.532 E00
θ_3 = 45	R/S	5	σ^f	D	606.419 E06
θ_4 = -45	R/S	4	$\sigma^{f'}$	R/S	684.799 E06
	A'	E_1^f = 76.080 E09			
DISPLAY E_i^f	R/S	62.542 E09	ENTER θ_t = 90	C	37
(optional)	R/S	213.704 E-3	t = 7	R/S	R_t = 228.559 E00
	R/S	17.830 E09	DISPLAY R_t'	R/S	1.160 E03
DISPLAY D_{ij}	B'	52.932 00	σ^f	D	342.839 E06
(optional)	R/S	43.555 00			
	"	9.492 00	$\sigma^{f'}$	R/S	1.740 E09
	"	11.985 00			
	"	1.674 00			
	"	1.674 00			
DISPLAY d_{ij}	R/S	19.716-03	ENTER θ_t = 45	C	37
(optional)	"	23.984-03	t = 6	R/S	R_t = 324.324 E00
	"	-4.213-03	DISPLAY R_t'	R/S	743.545 E00
	"	84.129-03	σ^f	D	486.486 E06
	"	-2.166-03	$\sigma^{f'}$	R/S	1.115 E09
	"	-2.762-03			
DISPLAY D_{ij}^*	C'	79.398 09			
(optional)	R/S	65.333 09			
	"	14.238 09			
	"	17.977 09			
	"	2.512 09			
	"	2.512 09			
DISPLAY d_{ij}^*	R/S	13.144-12			
(optional)	"	15.989-12			
	"	-2.809-12			
	"	56.086-12			
	"	-1.444-12			
	"	-1.842-12			

COMBO 3 SAMPLE PROBLEM #5: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2/90_2/45_2/-45_2]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER $n = 16$	A	8
$\theta_1 = 0$	R/S	7
.	.	.
.	.	.
.	.	.
$\theta_8 = -45$	R/S	E_1^f = 113.287 E09
DISPLAY E_i^f	R/S	65.334 E09
(optional)	R/S	98.770 E-3
	R/S	11.747 E09
DISPLAY D_{ij} (optional)	B'	76.842 00
	R/S	44.693 00
	"	5.216 00
	"	8.065 00
	"	2.679 00
	"	2.679 00
DISPLAY d_{ij} (optional)	R/S	13.241-03
	"	22.959-03
	"	-1.308-03
	"	127.697-03
	"	-3.964-03
	"	-7.192-03
DISPLAY D^*_{ij} (optional)	C'	115.263 09
	R/S	67.039 09
	"	7.825 09
	"	12.098 09
	"	4.019 09
	"	4.019 09
DISPLAY d^*_{ij} (optional)	R/S	8.827-12
	"	15.306-12
	"	-871.852-15
	"	85.132-12
	"	-2.643-12
	"	-4.795-12

PROCEDURE	KEY	DISPLAY
ENTER $M_1 = 1$	B	6.2
$M_2 = 0$	R/S	6.6
$M_6 = 0$	R/S	60
ENTER $\theta_t = 0$	C	37
$t = 8$	R/S	R_t = 545.875 E00
DISPLAY R'_t	R/S	762.093 E00
σ^f	D	818.812 E06
$\sigma^{f'}$	R/S	1.143 E09
ENTER $\theta_t = 90$	C	37
$t = 6$	R/S	R_t = 389.456 E00
DISPLAY R'_t	R/S	2.100 E03
σ^f	D	584.185 E06
$\sigma^{f'}$	R/S	3.150 E09
ENTER $\theta_t = 45$	C	37
$t = 4$	R/S	R_t = 671.467 E00
DISPLAY R'_t	R/S	1.970 E03
σ^f	D	1.007 E09
$\sigma^{f'}$	R/S	2.955 E09

COMBO 3 SAMPLE PROBLEM #6: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2/90_2/45_2/-45_2/C_8]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	DISPLAY
ENTER n = 32	A	16
θ_1 = 0	R/S	15
.		
.		
.		
θ_8 = -45	R/S	8
	A'	E_1^f = 76.080 E09
DISPLAY E_1^f	R/S	62.542 E09
(optional)	R/S	213.704 E-3
	R/S	17.830 E09
DISPLAY D_{ij}	B'	423.459 00
(optional)	R/S	348.443 00
	"	75.935 00
	"	95.876 00
	"	13.396 00
	"	13.396 00
DISPLAY d_{ij}	R/S	2.465-03
(optional)	"	2.998-03
	"	-526.677-06
	"	10.516-03
	"	-270.752-06
	"	-345.284-06
DISPLAY D^*_{ij}	C'	79.398 09
(optional)	R/S	65.333 09
	"	14.238 09
	"	17.977 09
	"	2.512 09
	"	2.512 09
DISPLAY d^*_{ij}	R/S	13.144-12
(optional)	"	15.989-12
	"	-2.809-12
	"	56.086-12
	"	-1.444-12
	"	-1.842-12

PROCEDURE	KEY	DISPLAY
ENTER M_1 = 1	B	6.2
M_2 = 0	R/S	6.6
M_6 = 0	R/S	60
ENTER θ_t = 0	C	37
t = 16	R/S	R_t = 1.617 E03
DISPLAY R_t'	R/S	1.826 E03
σ^f	D	606.419 E06
$\sigma^{f'}$	R/S	684.799 E06
ENTER θ_t = 90	C	37
t = 14		R_t = 914.237 E00
DISPLAY R_t'	R/S	4.639 E03
σ^f	D	342.839 E06
$\sigma^{f'}$	R/S	1.740 E09
ENTER θ_t = 45	C	37
t = 12	R/S	R_t = 1.297 E03
DISPLAY R_t'	R/S	2.974 E03
σ^f	D	486.486 E06
$\sigma^{f'}$	R/S	1.115 E09

SECTION VIII

COMBO 3P: FLEXURAL STIFFNESS AND STRENGTH OF SYMMETRIC LAMINATES WITH PRINTER

AFWAL/MLBM CARD MODULE FOR TI-59				
COMBO 3P: FLEXURAL PROPERTIES w/PRINTER				
Core				
$n, \theta_t \rightarrow E_i^f, D's$	$M_i \rightarrow k_i$	$\theta_t, t \rightarrow R_t, \sigma_t^f$		

Combo 3P is essentially the same program as Combo 3 with the addition of printing commands in the program. A series of sample problems are given at the end of this section. The entire program is listed in Appendix D.

To use Combo 3P:

1. Have U_i, G_{ij}, and h_o for the desired material and in the desired units stored in bank 3.
2. Press CLR, read side 1, press CLR, read side 2.
3. No core: Enter n, the total number of plies, then press A. Enter θ_1, R/S, θ_2, R/S,..., $\theta_{n/2}$, R/S. See Figure 26.
   Core: Enter n, the total number of plies plus the total number of ply thicknesses that make up the core, press A. Enter θ_1, R/S, θ_2, R/S,... After entering one angle for each ply orientation (note less than n entries), press A. See Figures 26 and 27 for details.

The machine calculates and prints:

$E_1^f, E_2^f, \nu_{21}^f, E_6^f$ Labeled "E*" by printer

$D_{11}, D_{22}, D_{12}, D_{16}, D_{26}$ Labeled "D" by printer

$d_{11}, d_{22}, d_{12}, d_{16}, d_{26}$

$D_{11}^*, D_{22}^*, D_{12}^*, D_{16}^*, D_{26}^*$ Labeled "D*" by printer

$d_{11}^*, d_{22}^*, d_{12}^*, d_{16}^*, d_{26}^*$

The definitions of the above quantities are given in the section describing Combo 3.

4. Enter M_1, M_2, M_6 (as shown in Figure 26) as selected unit loads or an actual loading case. This selection is discussed in detail in the Combo 3 section.
5. Enter θ_t and t, the orientation and the ply number of the ply to be examined.

The machine calculates and prints:

R_t, R_t' Labeled "R" by printer

$\sigma_t^f, \sigma_t^{f'}$ Labeled "Σ" by printer

The definitions of the above quantities are also given in the section describing Combo 3.

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
1	Enter ply data				
2a	Enter n	A		n	n/2
b	Θ_1	R/S		Θ_1	n/2 - 1
c	Θ_2	R/S		Θ_2	n/2 - 2
.	.	.		.	.
.	.	.		.	.
.	.	.		.	.
*	$\Theta_{n/2 - 1}$	R/S		$\Theta_{n/2 - 1}$	1
	$\Theta_{n/2}$	R/S		SYM	
			E*	E_1^f, E_2^f, ν_{21}^f, E_6^f	
			D	D_{11}, D_{22}, D_{12}, D_{66}, D_{16}, D_{26}	
				d_{11}, d_{22}, d_{12}, d_{66}, d_{16}, d_{26}	
			D*	D_{11}^*, D_{22}^*, D_{12}^*, D_{66}^*, D_{16}^*, D_{26}^*	
				d_{11}^*, d_{22}^*, d_{12}^*, d_{66}^*, d_{16}^*, d_{26}^*	6.1
3a	Enter M_1	B	M	M_1	6.2
b	M_2	R/S		M_2	6.6
c	M_6	R/S		M_6	60
4a	Enter Θ_t	C	↑, T	Θ_t	37
b	t	R/S		t	
			R	R_t, R_t'	
			Σ	σ_t^f, $\sigma_t^{f'}$	60

Figure 26. Combo 3P Instruction Chart

STEP	PROCEDURE	PRESS	PRINTER LABEL	PRINTOUT	DISPLAY
*	For sandwich construction			when display = c	
		A'	CR	c	
				SYM	
			E*	printout will continue as previously described in Step 1	6.1

Figure 27. Combo 3P Options

00	USED	15	D_{26}	30	U_1	45	G_{yy}
01	USED	16	d_{11}, G_{xx}	31	U_2	46	G_{xy}
02	USED	17	d_{22}, G_{yy}	32	U_3	47	G_{ss}
03	USED	18	d_{12}, G_{xy}	33	U_4	48	G_x
04	USED	19	d_{66}, G_{ss}	34	U_5	49	G_y
05	n, n/2, t	20	d_{16}, G_x	35	θ	50	
06	R_t	21	d_{26}, G_y	36	V_o	51	
07	R'_t	22	$\lvert D \rvert$	37	V_1	52	
08	$12/h^3$	23	k_1, ε_1	38	V_3	53	p
09	h	24	k_2, ε_2	39	V_2, $\sqrt{}$	54	q
10	D_{11}	25	k_6, ε_6	40	V_4	55	r
11	D_{22}	26	M_1, 0	41	θ	56	a
12	D_{12}	27	M_2, 0	42	USED	57	-b/2a
13	D_{66}	28	M_6, 0	43	USED	58	c/a
14	D_{16}	29	USED	44	G_{xx}	59	h_o

Figure 28. Combo 3P Storage Memories

COMBO CARD #3P
FLEXURAL STIFFNESS & STRENGTH
(ON PRINTER)

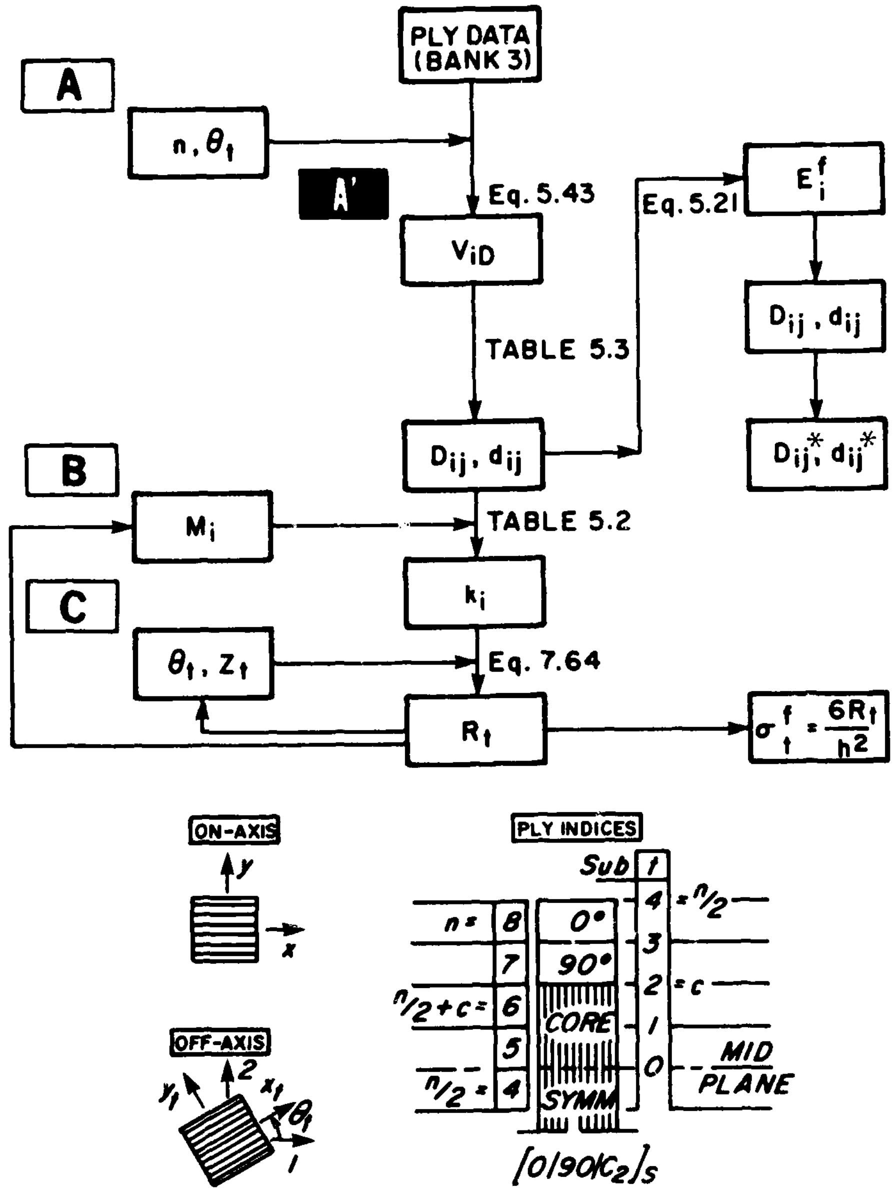


Figure 29. Combo 3P Flow Chart

AD-A117 869 AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH F/G 11/4
INSTRUCTIONS FOR TI-59 COMBINED CARD/MODULE CALCULATIONS FOR IN--ETC(U)
JUN 82 S L DONALDSON
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Combo 3P Sample Problems

As in the Combo 2 section, one should follow the instruction charts, Figures 26 and 27, when working through the sample problems. The sample problems should be followed vertically down the left half of the page, then the right. Note that the example problems' printer tape extends beyond the blocks describing the printer output. This corresponds to re-entering a new loading condition or examining a different ply orientation. The "looping" done here is best shown in the program diagram, Figure 29.

The entry of sample problems with a core is exactly the same as that described in Combo 2 and 2P. Again, a core that is a non-integer multiple of unit ply thickness is permissible. Problem #3 demonstrates this.

Additional units for this Combo are, in the case of the sample problems listed:

D_{ij}	N-m
d_{ij}	1/N-m
D^*_{ij}	N/m^2 (Pa)
d^*_{ij}	m^2/N (1/Pa)

English unit calculations can be completed just as easily. When the material properties in Bank 3 are stored in English units, loads can be entered in in-lbs/in, etc., provided their dimensions are consistent with the units used to enter the unit ply data.

The six sample problems are discussed below:

#1 The failure σ_t^f is calculated, then the failure moment $= h^2/6\ \sigma_t^f$ is applied to show $R_t = 1$ can be recovered.

#2 This laminate is the same as the one in example #1, except the inner plies have been separated by a core. Note

that for the same ply weight, the maximum moment allowable increases 250% from the original laminate.

#3 Increasing the core thickness further increases the maximum allowable bending moment. This example also demonstrates how to enter a core thickness that is not an integer multiple of unit ply thickness.

#4, #5, #6 This example shows that for the quasi-isotropic lay-up under bending w.r.t. the 1-axis only, the 90° ply fails first. By halving the ply weight and adding a core, 57.8% of the strength is recovered. Or, by taking the original #4 laminate and doubling its thickness with a core, its bending strength is 235% of what it was originally. The bending strength increase due to a lightweight core is obvious.

COMBO 3P SAMPLE PROBLEM #1: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2]_T$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	2. 00
ENTER θ_1	R/S	0.000 00 SYM
PRINT E_i^f		E* 181.000 09 10.300 09 280.000-03 7.170 09
PRINT D_{ij}		D 236.733-03 13.472-03 3.772-03 9.336-03 0.000 00 0.000 00
PRINT d_{ij}		4.243 00 74.563 00 -1.188 00 107.113 00 0.000 00 0.000 00
PRINT D^*_{ij}		D* 181.811 09 10.346 09 2.897 09 7.170 09 0.000 00 0.000 00
PRINT d^*_{ij}		5.525-12 97.087-12 -1.547-12 139.470-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER M_1 M_2 M_6	B R/S R/S	M 1.000 00 0.000 00 0.000 00
ENTER Θ_t t	C R/S	↑, T 0.000 00 1.000 00
PRINT R_t R'_t		R 15.625 00 15.625 00
PRINT σ^f $\sigma^{f'}$		Σ 1.500 09 1.500 09
		M 15.625 00 0.000 00 0.000 00 ↑, T 0.000 00 1.000 00 R 1.000 00 1.000 00 Σ 96.000 06 96.000 06

COMBO 3P SAMPLE PROBLEM #2: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/C]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	4. 00
ENTER θ_1	R/S A'	0.000 00 CR 1.000 00 SYM
PRINT E_i^f		E* 158.375 09 9.012 09 280.000-03 6.274 09
PRINT D_{ij}		D 1.657 00 94.301-03 26.404-03 65.352-03 0.000 00 0.000 00
PRINT d_{ij}		606.156-03 10.652 00 -169.724-03 15.302 00 0.000 00 0.000 00
PRINT D_{ij}^*		D* 159.085 09 9.053 09 2.535 09 6.274 09 0.000 00 0.000 00
PRINT d_{ij}^*		6.314-12 110.957-12 -1.768-12 159.394-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER M_1	B	M 1.000 00
M_2	R/S	0.000 00
M_6	R/S	0.000 00
ENTER Θ_t	C	↑, T 0.000 00
t	R/S	2.000 00
PRINT R_t		R 54.688 00
R_t'		54.688 00
PRINT σ^f		Σ 1.313 09
$\sigma^{f'}$		1.313 09
		M 54.688 00 0.000 00 0.000 00
		↑, T 0.000 00 2.000 00
		R 999.991-03 999.991-03
		Σ 24.000 06 24.000 06

COMBO 3P SAMPLE PROBLEM #3: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/C_{1.3}]_s$ **MATERIAL:** T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	4.6 00
ENTER θ_1	R/S A'	0.000 00 CR 1.300 00 SYM
PRINT E_i^f		E* 148.317 09 8.440 09 280.000-03 5.875 09
PRINT D_{ij}		D 2.360 00 134.311-03 37.607-03 93.079-03 0.000 00 0.000 00
PRINT d_{ij}		425.586-03 7.479 00 -119.164-03 10.744 00 0.000 00 0.000 00
PRINT D_{ij}^*		D* 148.981 09 8.478 09 2.374 09 5.875 09 0.000 00 0.000 00
PRINT d_{ij}^*		6.742-12 118.482-12 -1.888-12 170.204-12 0.000 00 0.000 00

PROCEDURE	KEY	PRINT
ENTER M_1	B	
M_2	R/S	M 1.000 00
M_6	R/S	0.000 00 0.000 00
ENTER Θ_t	C	†, T
t	R/S	0.000 00 2.300 00
PRINT R_t		R
R'_t		67.731 00 67.731 00
PRINT σ^f $\sigma^{f'}$		Σ 1.229 09 1.229 09
		M 67.731 00 0.000 00 0.000 00
		†, T 0.000 00 2.300 00
		R 1.000 00 1.000 00
		Σ 18.147 06 18.147 06

COMBO 3P SAMPLE PROBLEM #4: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2/90_2/45_2/-45_2]_s$ MATERIAL: T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	16.000 00
ENTER θ_1	R/S	0.000 00
.	.	0.000 00
.	.	90.000 00
.	.	90.000 00
.	.	45.000 00
.	.	45.000 00
.	.	-45.000 00
θ_8	R/S	-45.000 00
		SYM
PRINT E_i^f		E*
		113.287 09
		65.334 09
		98.770-03
		11.747 09
PRINT D_{ij}		D
		76.842 00
		44.693 00
		5.216 00
		8.065 00
		2.679 00
		2.679 00
PRINT d_{ij}		13.241-03
		22.959-03
		-1.308-03
		127.697-03
		-3.964-03
		-7.192-03
PRINT D_{ij}^*		D*
		115.263 09
		67.039 09
		7.825 09
		12.098 09
		4.019 09
		4.019 09
PRINT d_{ij}^*		8.827-12
		15.306-12
		-871.852-15
		85.132-12
		-2.643-12
		-4.795-12

PROCEDURE	KEY	PRINT
ENTER M_1	B	M
M_2	R/S	1.000 00
		0.000 00
M_6	R/S	0.000 00
ENTER Θ_t	C	†, T
		0.000 00
t	R/S	8.000 00
PRINT R_t		R
		545.875 00
R_t'		762.093 00
PRINT σ^f		Σ
$\sigma^{f'}$		818.812 06
		1.143 09
		†, T
		90.000 00
		6.000 00
		R
		389.456 00
		2.100 03
		Σ
		584.185 06
		3.150 09
		†, T
		45.000 00
		4.000 00
		R
		671.467 00
		1.970 03
		Σ
		1.007 09
		2.955 09

COMBO 3P SAMPLE PROBLEM #5: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0/90/45/-45/C_4]_s$ **MATERIAL:** T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	16.000 00
ENTER θ_1 θ_2 θ_3 θ_4	R/S R/S R/S R/S A'	0.000 00 90.000 00 45.000 00 -45.000 00 CR 4.000 00 SYM
PRINT E_i^f		E* 76.080 09 62.542 09 213.704-03 17.830 09
PRINT D_{ij}		D 52.932 00 43.555 00 9.492 00 11.985 00 1.674 00 1.674 00
PRINT d_{ij}		19.716-03 23.984-03 -4.213-03 84.129-03 -2.166-03 -2.762-03
PRINT D_{ij}^*		D* 79.398 09 65.333 09 14.238 09 17.977 09 2.512 09 2.512 09
PRINT d_{ij}^*		13.144-12 15.989-12 -2.809-12 56.086-12 -1.444-12 -1.842-12

PROCEDURE	KEY	PRINT
ENTER M_1 M_2 M_6	B R/S R/S	M 1.000 00 0.000 00 0.000 00
ENTER Θ_t t	C R/S	↑, T 0.000 00 8.000 00
PRINT R_t R_t'		R 404.279 00 456.532 00
PRINT σ^f $\sigma^{f'}$		Σ 606.419 06 684.799 06
		↑, T 90.000 00 7.000 00
		R 228.559 00 1.160 03
		Σ 342.839 06 1.740 09
		↑, T 45.000 00 6.000 00
		R 324.324 00 743.545 00
		Σ 486.486 06 1.115 09

COMBO 3P SAMPLE PROBLEM #6: FLEXURAL STIFFNESS AND STRENGTH

LAMINATE: $[0_2/90_2/45_2/-45_2/C_8]_s$ **MATERIAL:** T300/5208

PROCEDURE	KEY	PRINT
ENTER n	A	32.000 00
ENTER θ_1	R/S	0.000 00
.	.	0.000 00
.	.	90.000 00
.	.	90.000 00
.	.	45.000 00
.	.	45.000 00
.	.	-45.000 00
θ_8	R/S	-45.000 00
	A'	CR
		8.000 00
		SYM
PRINT E_i^f		E*
		76.080 09
		62.542 09
		213.704-03
		17.830 09
PRINT D_{ij}		D
		423.459 00
		348.443 00
		75.935 00
		95.876 00
		13.396 00
		13.396 00
PRINT d_{ij}		2.465-03
		2.998-03
		-526.677-06
		10.516-03
		-270.752-06
		-345.284-06
PRINT D^*_{ij}		D*
		79.398 09
		65.333 09
		14.238 09
		17.977 09
		2.512 09
		2.512 09
PRINT d^*_{ij}		13.144-12
		15.989-12
		-2.809-12
		56.086-12
		-1.444-12
		-1.842-12

PROCEDURE	KEY	PRINT
ENTER M_1	B	M
		1.000 00
M_2	R/S	0.000 00
M_6	R/S	0.000 00
ENTER Θ_t	C	†, T
		0.000 00
t	R/S	16.000 00
PRINT R_t		R
		1.617 03
R'_t		1.826 03
PRINT σ^f		Σ
		606.419 06
$\sigma^{f'}$		684.799 06
		†, T
		90.000 00
		14.000 00
		R
		914.237 00
		4.639 03
		Σ
		342.839 06
		1.740 09
		†, T
		45.000 00
		12.000 00
		R
		1.297 03
		2.974 03
		Σ
		486.486 06
		1.115 09

APPENDIX A

Description of Applied and Resultant Stress and Strain

Any combination of six different loads can be applied to the desired laminate (see Figure A-8). Three in-plane loads can be applied using Combo 2 or 2P, and three flexural loads can be applied using Combo 3 or 3P. Combined loading (simultaneous in-plane and flexural loading) can be done with the existing Combo cards, using the explanation given in Appendix B. The following sections describe the stresses and strains for in-plane, flexural, and combined loading cases. All drawings are for a sample $[0/90/45/-45]_s$ laminate, loaded uniaxially in the 1-direction. All figures are drawn with respect to the 1-direction (σ_1, ε_1, etc). One could also load the laminate with respect to the 1, 2 (normal), and 6 (shear) references and examine the results in any of the 1, 2 and 6 references.

In-Plane:

All Combos are based on the plate under plane stress assumptions. The applied stresses are:

$$\bar{\sigma}_1 = 1/h \int_{-h/2}^{h/2} \sigma_1 dz$$

$$\bar{\sigma}_2 = 1/h \int_{-h/2}^{h/2} \sigma_2 dz$$

$$\bar{\sigma}_6 = 1/h \int_{-h/2}^{h/2} \sigma_6 dz$$

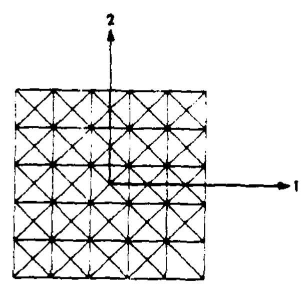


Figure A-1

These average stresses are often multiplied by laminate thickness.

$$N_1 = \bar{\sigma}_1 h$$
$$N_2 = \bar{\sigma}_2 h$$
$$N_6 = \bar{\sigma}_6 h$$

These average applied stresses are actually re-distributed in the laminate, ply-by-ply. This is because the resultant strain is constant across the laminate (see Figure A-3), but the stiffness matrices, [Q] (in the 1-2 system) vary according to ply orientation angle. The resultant stress distribution may look like:

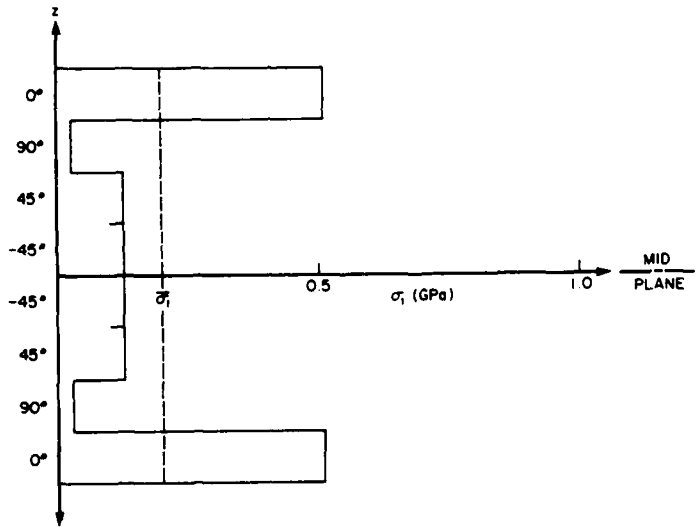


Figure A-2

Because of the thin plate assumption, the resulting strain is constant through the laminate thickness:

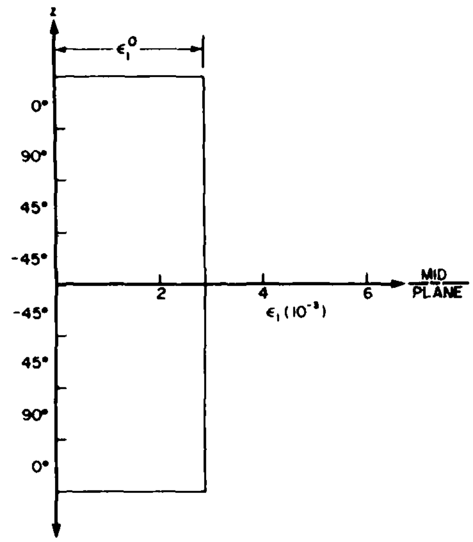


Figure A-3

The laminate stretches but does not curve or warp.

Flexural:

Bending moments applied to a laminate are similarly only average moments:

$$M_1 = \int_{-h/2}^{h/2} \sigma_1 z dz$$

$$M_2 = \int_{-h/2}^{h/2} \sigma_2 z dz$$

$$M_6 = \int_{-h/2}^{h/2} \sigma_6 z dz$$

The applied moments distribute themselves as stresses that vary ply-to-ply and linearly through each ply thickness:

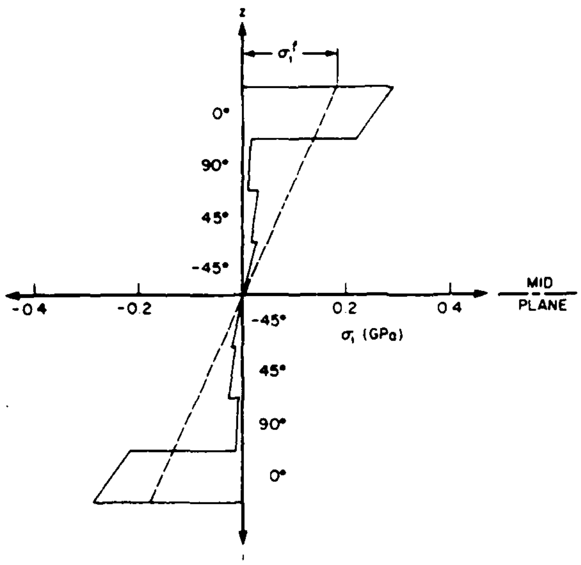


Figure A-4

The M_i, actually a combination of weighted stresses that vary through the thickness can be thought of as an averaged moment that varies linearly through the thickness. This gives rise to an averaged surface stress, σ_i^f:

$$M_i = 2 \text{ (area)(moment arm)}$$
$$= 2\ [1/2(h/2)\ \sigma_i^f\ h/3]$$
$$= h^2/6\ \sigma_i^f$$

These produce a linearly varying strain:

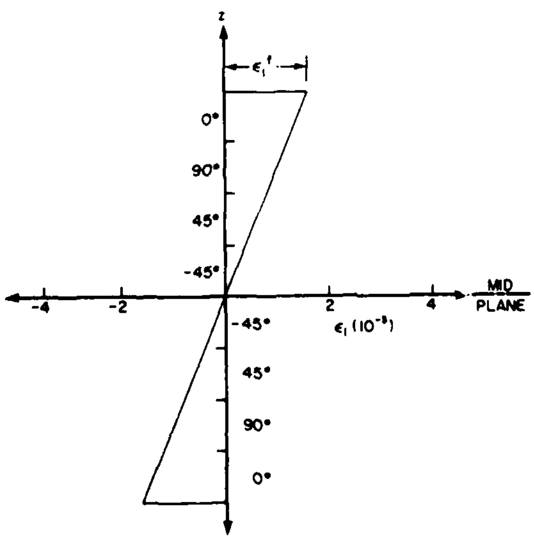


Figure A-5

The laminate curves but does not stretch along its centerline.

Combined In-Plane and Flexural:

Strain across the laminate thickness is simply a sum of the in-plane and flexural strain:

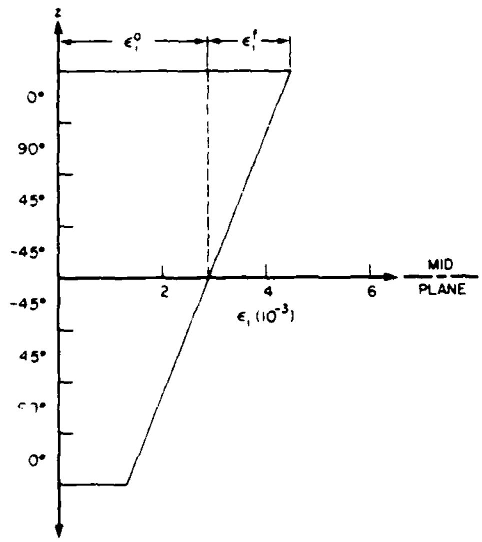


Figure A-6

The stress across the laminate can be related to this strain via the off-axis stiffness matrix for each ply:

$$\{\sigma_i\}_t = [Q]_t\{\varepsilon_i\}_t$$

$$= [Q]_t\{\varepsilon_i^o + \varepsilon_i^f\}_t$$

$$= [Q]_t\{\varepsilon_i^o\}_t + [Q]_t\{\varepsilon_i^f\}_t$$

$$= [Q]_t\{\varepsilon_i^o\}_t + z[Q]_t\{k_i\}_t$$

Stress, therefore, is also a simple addition of the in-plane and flexural stress. This would appear as:

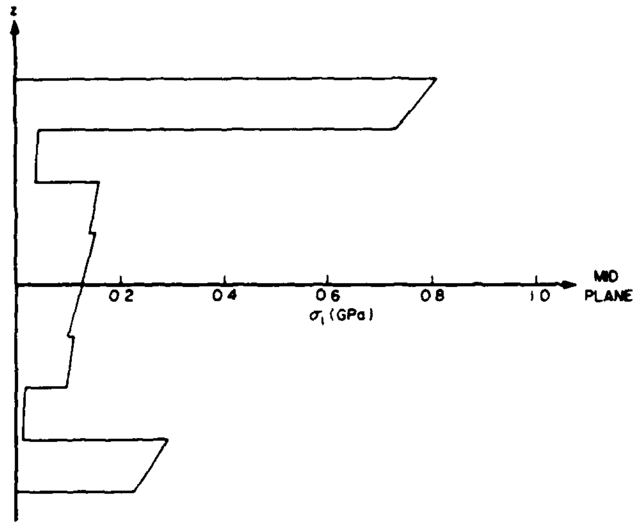
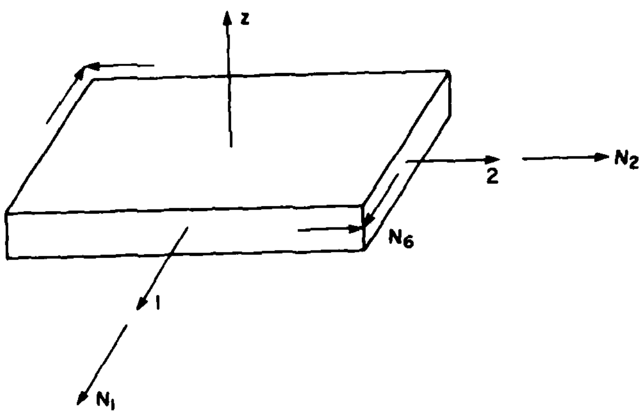
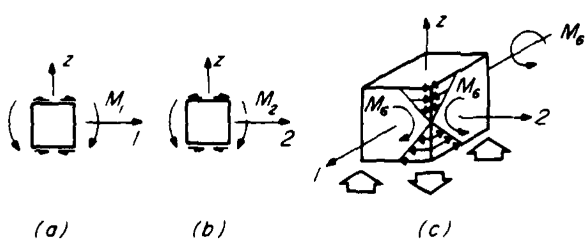


Figure A-7





The positive directions of components of moment. Bending moments are shown in (*a*) and (*b*). In (*c*), positive twisting moment appears as clockwise torque on the positive 1-axis face; counterclockwise on the positive 2-axis face. The effect of the positive twisting moment can be duplicated by four self-equilibrating forces acting at the corners as shown.

Figure A-8: Positive In-Plane and Flexural Loading Directions.

APPENDIX B

Instructions for Combined In-Plane and Flexural Loadings

The Combo cards discussed in the preceding sections, together with the *Composite Materials Module*, can also calculate strength ratios for laminated plates under combined in-plane and flexural loading conditions. The procedure used to do this is best illustrated with an example:

> It is desired that a $[0/90/45/-45]_s$, T300/5208 laminate carry the following loads:
>
> $N_1 = 200 \times 10^3$ N/m
>
> $N_2 = 0$
>
> $N_6 = 0$
>
> $M_1 = 30$ N-m/m
>
> $M_2 = 0$
>
> $M_6 = 0$
>
> Is this an allowable loading? What are the safety factors?

These questions are answered by calculating strength ratios for each ply. This is done with the following steps:

1. Use Combo 2 or 2P to enter the laminate stacking and in-plane loading, N_i. Recall the ε_i^o from registers 23, 24 and 25 by pressing **RCL** **2** **3** , etc (see Figure 16). This gives:

   $\varepsilon_1^o = 2.870 \times 10^{-3}$

   $\varepsilon_2^o = -849.7 \times 10^{-6}$

   $\varepsilon_6^o = 0$

   These strains are constant for all plies in the laminate (see Figure A-3).

2. Use Combo 3 or 3P to enter the laminate stacking and flexural loading, M_i. Recall the k_i from registers 23, 24 and 25:

$k_1 = 3.178$ 1/m

$k_2 = -313.9 \times 10^{-3}$

$k_6 = -951.4 \times 10^{-3}$

Using:

$\varepsilon_i = \varepsilon_i^{\circ} + zk_i$ (see Figure A-6).

$z = th_0$

Calculate for each ply ($h_0 = 125 \times 10^{-6}$ m):

$\theta_t = 0°$, $t = 4$ $\varepsilon_1 = 4.459 \times 10^{-3}$

$\varepsilon_2 = -1.006 \times 10^{-3}$

$\varepsilon_6 = -475.7 \times 10^{-6}$

$\theta_t = 90°$, $t = 3$ $\varepsilon_1 = 4.062 \times 10^{-3}$

$\varepsilon_2 = -967.4 \times 10^{-6}$

$\varepsilon_6 = -356.8 \times 10^{-6}$

$\theta_t = 45°$; $t = 2$ $\varepsilon_1 = 3.665 \times 10^{-3}$

$\varepsilon_2 = -928.2 \times 10^{-6}$

$\varepsilon_6 = -237.9 \times 10^{-6}$

$\theta_t = -45°$; $t = 1$ $\varepsilon_1 = 3.267 \times 10^{-3}$

$\varepsilon_2 = -888.9 \times 10^{-6}$

$\varepsilon_6 = -118.9 \times 10^{-6}$

These are the strains in the outermost surface of each ply due to the combined loading. Recall that Combo 2 has the ability to input strains directly to calculate strength ratios (Combo 2P cannot do this). Therefore:

3. Read in Combo 2, then enter the laminate stacking. Enter the ε_i for each of the plies using the $\boxed{E}$ button as shown in Figure 12. Record the R_t values. For this example, they are:

$R_0 = 1.800$

$R_{90} = .972$

$R_{45} = 1.33$

$R_{-45} = 1.54$

If one were to examine the strength ratios for the given in-plane loading only or flexural loading only, none of the plies would fail. However, the combination of loads will cause the 90° ply to fail ($R \leq 1$). To avoid failure, the loads would have to be reduced, or, to carry the original loads, the laminate stacking should be modified.

APPENDIX C

Instructions for Keying in a Program

1. Turn on calculator.
2. Press [LRN], display shows 000 00.
3. Begin key punching. Press the key label that corresponds to the program step desired. The calculator will automatically advance to the next line number.
4. Continue with entire program.
5. Press [LRN]. The display should return to normal.
6. Press [1] [2nd] [illegible] .* The display will go blank. Insert card, right-side-up, into the slot on the right side of the calculator. Retrieve card on the left side.
7. Press [2] [2nd] [illegible] . Insert the card upside-down into the slot. Retrieve card.
8. Label card accordingly.

If you make any errors, you can easily "edit" the program without *having to re-key the entire program.* Consult TI-59 owner's manual for information.

* The calculator will not write onto magnetic cards if the calculator is in a "fixed" format display mode (i.e., the number of digits displayed has been previously set). If the display flashes after attempting to record a card, the card did not record. Press [CLR] [INV] [2nd] [illegible] . This removes the fixed format. Repeat the card recording procedure as before.

APPENDIX D

Program Listings

COMBO 0: Selected Ply Data without Printer

Step	Code	Key	
000	76	LBL	T300-
001	11	A	5208
002	47	CMS	
003	57	ENG	
004	01	1	
005	08	8	
006	01	1	E_x
007	52	EE	
008	09	9	
009	42	STO	
010	25	25	
011	01	1	
012	00	0	
013	03	3	
014	52	EE	E_y
015	08	8	
016	42	STO	
017	26	26	
018	07	7	
019	01	1	
020	07	7	
021	52	EE	E_s
022	07	7	
023	42	STO	
024	27	27	
025	93	.	
026	02	2	
027	08	8	ν_x
028	42	STO	
029	28	28	
030	01	1	
031	02	2	
032	05	5	
033	52	EE	h_o
034	06	6	
035	94	+/-	
036	42	STO	
037	59	59	
038	71	SBR	
039	35	1/X	
040	36	PGM	
041	08	08	$X_{,...}$
042	10	E'	
043	71	SBR	
044	45	YX	
045	76	LBL	
046	35	1/X	
047	36	PGM	
048	01	01	Q_{ij}
049	71	SBR	
050	57	ENG	
051	36	PGM	
052	01	01	U_i
053	71	SBR	
054	52	EE	
055	92	RTN	
056	76	LBL	
057	45	YX	
058	36	PGM	
059	08	08	
060	71	SBR	F_{ij}
061	98	ADV	
062	36	PGM	
063	08	08	
064	71	SBR	G_{ij}
065	80	GRD	
066	43	RCL	
067	16	16	
068	42	STO	
069	44	44	
070	43	RCL	
071	17	17	
072	42	STO	
073	45	45	
074	43	RCL	
075	18	18	
076	42	STO	
077	46	46	
078	43	RCL	
079	19	19	
080	42	STO	
081	47	47	
082	43	RCL	
083	20	20	
084	42	STO	
085	48	48	
086	43	RCL	
087	21	21	
088	42	STO	
089	49	49	
090	91	R/S	
091	76	LBL	
092	13	C	AS-
093	47	CMS	3501
094	57	ENG	
095	01	1	
096	03	3	
097	08	8	
098	52	EE	
099	09	9	
100	42	STO	
101	25	25	
102	08	8	
103	09	9	
104	06	6	
105	52	EE	
106	07	7	
107	42	STO	
108	26	26	
109	07	7	
110	01	1	
111	52	EE	
112	08	8	
113	42	STO	
114	27	27	
115	93	.	
116	03	3	
117	42	STO	
118	28	28	
119	01	1	
120	02	2	
121	05	5	
122	52	EE	
123	06	6	
124	94	+/-	
125	42	STO	
126	59	59	
127	71	SBR	
128	35	1/X	
129	01	1	
130	04	4	
131	04	4	
132	07	7	
133	52	EE	
134	06	6	
135	42	STO	
136	23	23	
137	42	STO	
138	24	24	
139	05	5	
140	01	1	
141	07	7	
142	52	EE	
143	05	5	
144	42	STO	
145	25	25	
146	02	2	
147	00	0	
148	06	6	
149	52	EE	
150	06	6	
151	42	STO	
152	26	26	
153	09	9	
154	03	3	
155	52	EE	
156	06	6	
157	42	STO	
158	27	27	
159	93	.	
160	05	5	
161	94	+/-	
162	42	STO	
163	28	28	
164	71	SBR	
165	45	YX	
166	76	LBL	
167	14	D	Scotch-
168	47	CMS	ply
169	57	ENG	1002
170	03	3	
171	08	8	
172	06	6	
173	52	EE	
174	08	8	
175	42	STO	
176	25	25	
177	08	8	
178	02	2	
179	07	7	
180	52	EE	
181	07	7	
182	42	STO	
183	26	26	
184	04	4	
185	01	1	
186	04	4	
187	52	EE	
188	07	7	
189	42	STO	
190	27	27	
191	93	.	
192	02	2	
193	06	6	
194	42	STO	
195	28	28	
196	01	1	
197	02	2	
198	05	5	
199	52	EE	
200	06	6	
201	94	+/-	
202	42	STO	
203	59	59	
204	71	SBR	
205	35	1/X	
206	01	1	
207	00	0	
208	06	6	
209	02	2	
210	52	EE	
211	06	6	
212	42	STO	
213	23	23	
214	06	6	
215	01	1	
216	52	EE	
217	07	7	
218	42	STO	
219	24	24	
220	03	3	
221	01	1	
222	52	EE	
223	06	6	
224	42	STO	
225	25	25	
226	01	1	
227	01	1	
228	08	8	
229	52	EE	
230	06	6	
231	42	STO	
232	26	26	
233	07	7	
234	02	2	
235	52	EE	
236	06	6	
237	42	STO	
238	27	27	
239	93		

240	05	5	
241	94	+/-	
242	42	STO	
243	28	28	
244	71	SBR	
245	45	Y^X	
246	76	LBL	
247	16	A'	Al
248	47	CMS	
249	57	ENG	
250	06	6	
251	09	9	
252	52	EE	
253	09	9	
254	42	STO	
255	25	25	
256	42	STO	
257	26	26	
258	55	÷	
259	02	2	
260	93	.	
261	06	6	
262	95	=	
263	42	STO	
264	27	27	
265	93	.	
266	03	3	
267	42	STO	
268	28	28	
269	01	1	
270	42	STO	
271	59	59	
272	71	SBR	
273	35	1/X	
274	04	4	
275	52	EE	
276	08	8	
277	42	STO	
278	23	23	
279	42	STO	
280	24	24	
281	42	STO	
282	25	25	
283	42	STO	
284	26	26	
285	02	2	
286	03	3	
287	52	EE	
288	07	7	
289	42	STO	
290	27	27	
291	93	.	
292	05	5	
293	94	+/-	
294	42	STO	
295	28	28	
296	71	SBR	
297	45	Y^X	
298	76	LBL	
299	10	E'	

300	06	6	
301	08	8	SI →
302	09	9	Engl.
303	05	5	
304	35	1/X	
305	49	PRD	
306	30	30	
307	49	PRD	
308	31	31	
309	49	PRD	
310	32	32	
311	49	PRD	
312	33	33	
313	49	PRD	
314	34	34	
315	95	=	
316	03	3	
317	09	9	
318	93	.	
319	04	4	
320	49	PRD	
321	59	59	
322	91	R/S	
323	76	LBL	
324	12	B	B(4)/
325	47	CMS	5505
326	57	ENG	
327	02	2	
328	00	0	
329	04	4	
330	52	EE	
331	09	9	
332	42	STO	
333	25	25	
334	01	1	
335	08	8	
336	93	.	
337	05	5	
338	52	EE	
339	09	9	
340	42	STO	
341	26	26	
342	93	.	
343	02	2	
344	03	3	
345	42	STO	
346	28	28	
347	05	5	
348	93	.	
349	05	5	
350	09	9	
351	52	EE	
352	09	9	
353	42	STO	
354	27	27	
355	01	1	
356	02	2	
357	05	5	
358	52	EE	
359	06	6	

360	94	+/-	
361	42	STO	
362	59	59	
363	71	SBR	
364	35	1/X	
365	01	1	
366	02	2	
367	06	6	
368	52	EE	
369	07	7	
370	42	STO	
371	23	23	
372	02	2	
373	05	5	
374	52	EE	
375	08	8	
376	42	STO	
377	24	24	
378	06	6	
379	01	1	
380	52	EE	
381	06	6	
382	42	STO	
383	25	25	
384	02	2	
385	00	0	
386	02	2	
387	52	EE	
388	06	6	
389	42	STO	
390	26	26	
391	06	6	
392	07	7	
393	52	EE	
394	06	6	
395	42	STO	
396	27	27	
397	93	.	
398	05	5	
399	94	+/-	
400	42	STO	
401	28	28	
402	71	SBR	
403	45	Y^X	
404	76	LBL	
405	15	E	Kevlar
406	47	CMS	49 -
407	57	ENG	
408	07	7	Epoxy
409	06	6	
410	52	EE	
411	09	9	
412	42	STO	
413	25	25	
414	05	5	
415	05	5	
416	52	EE	
417	08	8	
418	42	STO	
419	26	26	

420	02	2	
421	03	3	
422	52	EE	
423	08	8	
424	42	STO	
425	27	27	
426	93	.	
427	03	3	
428	04	4	
429	42	STO	
430	28	28	
431	01	1	
432	02	2	
433	05	5	
434	52	EE	
435	06	6	
436	94	+/-	
437	42	STO	
438	59	59	
439	71	SBR	
440	35	1/X	
441	01	1	
442	04	4	
443	52	EE	
444	08	8	
445	42	STO	
446	23	23	
447	02	2	
448	03	3	
449	05	5	
450	52	EE	
451	06	6	
452	42	STO	
453	24	24	
454	01	1	
455	02	2	
456	52	EE	
457	06	6	
458	42	STO	
459	25	25	
460	05	5	
461	03	3	
462	52	EE	
463	06	6	
464	42	STO	
465	26	26	
466	03	3	
467	04	4	
468	52	EE	
469	06	6	
470	42	STO	
471	27	27	
472	93	.	
473	05	5	
474	94	+/-	
475	42	STO	
476	28	28	
477	71	SBR	
478	45	Y^X	
479	00	0	

COMBO 1: User Input Ply Data without Printer

000	76	LBL	
001	11	A	
002	47	CMS	
003	57	ENG	
004	58	FIX	
005	03	03	
006	42	STO	
007	25	25	E_x
008	04	4	
009	95	=	
010	91	R/S	
011	42	STO	
012	26	26	E_y
013	03	3	
014	95	=	
015	91	R/S	
016	42	STO	
017	28	28	ν_x
018	02	2	
019	95	=	
020	91	R/S	
021	42	STO	
022	27	27	E_s
023	01	1	
024	95	=	
025	91	R/S	
026	42	STO	
027	59	59	h_o
028	36	PGM	
029	01	01	Q_{ij}
030	71	SBR	
031	57	ENG	
032	36	PGM	
033	11	11	S_{ij}
034	71	SBR	
035	35	1/X	
036	36	PGM	
037	01	01	U_i
038	71	SBR	
039	52	EE	
040	01	1	
041	93	.	
042	01	1	
043	95	=	
044	91	R/S	
045	76	LBL	Display Q_{ij} and S_{ij}
046	16	A'	
047	43	RCL	
048	10	10	
049	91	R/S	
050	43	RCL	
051	11	11	
052	91	R/S	
053	43	RCL	
054	12	12	
055	91	R/S	
056	43	RCL	
057	13	13	
058	91	R/S	
059	43	RCL	
060	16	16	
061	91	R/S	
062	43	RCL	
063	17	17	
064	91	R/S	
065	43	RCL	
066	18	18	
067	91	R/S	
068	43	RCL	
069	19	19	
070	91	R/S	
071	01	1	
072	93	.	
073	02	2	
074	95	=	
075	91	R/S	
076	76	LBL	Display U_i
077	17	B'	
078	43	RCL	
079	30	30	
080	91	R/S	
081	43	RCL	
082	31	31	
083	91	R/S	
084	43	RCL	
085	32	32	
086	91	R/S	
087	43	RCL	
088	33	33	
089	91	R/S	
090	43	RCL	
091	34	34	
092	91	R/S	
093	01	1	
094	93	.	
095	03	3	
096	95	=	
097	91	R/S	
098	76	LBL	Calculate and Display A_{ij} and a_{ij}
099	18	C'	
100	43	RCL	
101	10	10	
102	65	×	
103	43	RCL	
104	59	59	
105	95	=	
106	91	R/S	
107	43	RCL	
108	11	11	
109	65	×	
110	43	RCL	
111	59	59	
112	95	=	
113	91	R/S	
114	43	RCL	
115	12	12	
116	65	×	
117	43	RCL	
118	59	59	
119	95	=	
120	91	R/S	
121	43	RCL	
122	13	13	
123	65	×	
124	43	RCL	
125	59	59	
126	95	=	
127	91	R/S	
128	43	RCL	
129	16	16	
130	55	÷	
131	43	RCL	
132	59	59	
133	95	=	
134	91	R/S	
135	43	RCL	
136	17	17	
137	55	÷	
138	43	RCL	
139	59	59	
140	95	=	
141	91	R/S	
142	43	RCL	
143	18	18	
144	55	÷	
145	43	RCL	
146	59	59	
147	95	=	
148	91	R/S	
149	43	RCL	
150	19	19	
151	55	÷	
152	43	RCL	
153	59	59	
154	95	=	
155	91	R/S	
156	01	1	
157	93	.	
158	04	4	
159	95	=	
160	91	R/S	
161	76	LBL	
162	12	B	
163	57	ENG	
164	58	FIX	
165	03	03	
166	42	STO	
167	23	23	X
168	05	5	
169	95	=	
170	91	R/S	
171	42	STO	
172	24	24	X'
173	04	4	
174	95	=	
175	91	R/S	
176	42	STO	
177	25	25	Y
178	03	3	
179	95	=	
180	91	R/S	
181	42	STO	Y'
182	26	26	
183	02	2	
184	95	=	
185	91	R/S	
186	42	STO	
187	27	27	S
188	01	1	
189	95	=	
190	91	R/S	
191	42	STO	
192	28	28	F_{xy}^*
193	36	PGM	
194	08	08	F_{ij}
195	71	SBR	
196	98	ADV	
197	36	PGM	
198	08	08	G_{ij}
199	71	SBR	
200	80	GRD	
201	43	RCL	Transfer F_{ij} and G_{ij}
202	44	44	
203	42	STO	
204	51	51	
205	43	RCL	
206	45	45	
207	42	STO	
208	52	52	
209	43	RCL	
210	46	46	
211	42	STO	
212	53	53	
213	43	RCL	
214	47	47	
215	42	STO	
216	54	54	
217	43	RCL	
218	48	48	
219	42	STO	
220	55	55	
221	43	RCL	
222	49	49	
223	42	STO	
224	56	56	
225	43	RCL	
226	16	16	
227	42	STO	
228	44	44	
229	43	RCL	
230	17	17	
231	42	STO	
232	45	45	
233	43	RCL	
234	18	18	
235	42	STO	
236	46	46	
237	43	RCL	
238	19	19	
239	42	STO	

240	47	47	
241	43	RCL	
242	20	20	
243	42	STO	
244	48	48	
245	43	RCL	
246	21	21	
247	42	STO	
248	49	49	
249	01	1	
250	93	.	
251	05	5	
252	95	=	
253	91	R/S	
254	76	LBL	
255	19	D'	
256	43	RCL	
257	51	51	
258	91	R/S	
259	43	RCL	
260	52	52	
261	91	R/S	
262	43	RCL	
263	53	53	
264	91	R/S	
265	43	RCL	
266	54	54	
267	91	R/S	
268	43	RCL	Display Fij
269	55	55	
270	91	R/S	
271	43	RCL	
272	56	56	
273	91	R/S	
274	01	1	
275	93	.	
276	06	6	
277	95	=	
278	91	R/S	
279	76	LBL	
280	10	E'	
281	43	RCL	
282	44	44	
283	91	R/S	
284	43	RCL	
285	45	45	
286	91	R/S	
287	43	RCL	
288	46	46	
289	91	R/S	
290	43	RCL	Display Gij
291	47	47	
292	91	R/S	
293	43	RCL	
294	48	48	
295	91	R/S	
296	43	RCL	
297	49	49	
298	91	R/S	
299	01	1	

300	93	.	
301	07	7	
302	95	=	
303	91	R/S	
304	76	LBL	
305	13	C	
306	06	6	SI→ Engl.
307	08	8	
308	09	9	
309	05	5	
310	35	1/X	
311	49	PRD	
312	30	30	
313	49	PRD	
314	31	31	
315	49	PRD	
316	32	32	
317	49	PRD	
318	33	33	
319	49	PRD	
320	34	34	
321	95	=	
322	03	3	
323	09	9	
324	93	.	
325	04	4	
326	49	PRD	
327	59	59	
328	43	RCL	
329	59	59	
330	95	=	
331	91	R/S	
332	76	LBL	
333	14	D	
334	06	6	Engl→ SI
335	08	8	
336	09	9	
337	05	5	
338	49	PRD	
339	30	30	
340	49	PRD	
341	31	31	
342	49	PRD	
343	32	32	
344	49	PRD	
345	33	33	
346	49	PRD	
347	34	34	
348	95	=	
349	03	3	
350	09	9	
351	93	.	
352	04	4	
353	35	1/X	
354	49	PRD	
355	59	59	
356	43	RCL	
357	59	59	
358	95	=	
359	91	R/S	

COMBO 1P: User Input Ply Data with Printer

Loc	Code	Key	
000	76	LBL	
001	11	A	
002	47	CMS	
003	42	STO	E_x
004	25	25	
005	57	ENG	
006	58	FIX	
007	03	03	
008	01	1	
009	07	7	
010	00	0	
011	00	0	
012	42	STO	
013	02	02	
014	36	PGM	
015	11	11	
016	71	SBR	
017	90	LST	
018	43	RCL	
019	25	25	
020	99	PRT	
021	04	4	
022	95	=	
023	91	R/S	
024	42	STO	E_y
025	26	26	
026	99	PRT	
027	03	3	
028	95	=	
029	91	R/S	
030	42	STO	ν_x
031	28	28	
032	99	PRT	
033	02	2	
034	95	=	
035	91	R/S	
036	42	STO	E_s
037	27	27	
038	99	PRT	
039	98	ADV	
040	01	1	
041	95	=	
042	91	R/S	
043	42	STO	h_0
044	59	59	
045	02	2	
046	03	3	
047	00	0	
048	00	0	
049	42	STO	
050	02	02	
051	36	PGM	
052	11	11	
053	71	SBR	
054	90	LST	
055	43	RCL	
056	59	59	
057	99	PRT	
058	98	ADV	
059	36	PGM	

Loc	Code	Key	
060	01	01	
061	71	SBR	Q_{ij}
062	57	ENG	
063	03	3	
064	04	4	
065	00	0	
066	00	0	
067	42	STO	
068	02	02	
069	36	PGM	
070	11	11	
071	71	SBR	
072	90	LST	
073	43	RCL	
074	10	10	
075	99	PRT	Print Q_{ij}
076	43	RCL	
077	11	11	
078	99	PRT	
079	43	RCL	
080	12	12	
081	99	PRT	
082	43	RCL	
083	13	13	
084	99	PRT	
085	98	ADV	
086	36	PGM	
087	11	11	S_{ij}
088	71	SBR	
089	35	1/X	
090	03	3	
091	06	6	
092	00	0	
093	00	0	
094	42	STO	
095	02	02	
096	36	PGM	
097	11	11	
098	71	SBR	
099	90	LST	
100	43	RCL	
101	16	16	Print S_{ij}
102	99	PRT	
103	43	RCL	
104	17	17	
105	99	PRT	
106	43	RCL	
107	18	18	
108	99	PRT	
109	43	RCL	
110	19	19	
111	99	PRT	
112	98	ADV	
113	36	PGM	
114	01	01	U_i
115	71	SBR	
116	52	EE	
117	04	4	
118	01	1	
119	00	0	111

Loc	Code	Key	
120	00	0	
121	42	STO	
122	02	02	
123	36	PGM	
124	11	11	
125	71	SBR	
126	90	LST	
127	43	RCL	
128	30	30	
129	99	PRT	
130	43	RCL	
131	31	31	
132	99	PRT	
133	43	RCL	
134	32	32	
135	99	PRT	
136	43	RCL	Print U_i
137	33	33	
138	99	PRT	
139	43	RCL	
140	34	34	
141	99	PRT	
142	98	ADV	
143	01	1	
144	03	3	
145	00	0	
146	00	0	
147	42	STO	
148	02	02	
149	36	PGM	
150	11	11	
151	71	SBR	
152	90	LST	
153	43	RCL	
154	10	10	
155	65	×	
156	43	RCL	
157	59	59	
158	95	=	
159	99	PRT	
160	43	RCL	Calculate and Print A_{ij}
161	11	11	
162	65	×	
163	43	RCL	
164	59	59	
165	95	=	
166	99	PRT	
167	43	RCL	
168	12	12	
169	65	×	
170	43	RCL	
171	59	59	
172	95	=	
173	99	PRT	
174	43	RCL	
175	13	13	
176	65	×	
177	43	RCL	
178	59	59	
179	95	=	

Loc	Code	Key	
180	99	PRT	
181	98	ADV	
182	01	1	
183	03	3	
184	02	2	
185	04	4	
186	42	STO	
187	02	02	
188	36	PGM	
189	11	11	
190	71	SBR	
191	90	LST	
192	43	RCL	
193	16	16	
194	55	÷	
195	43	RCL	
196	59	59	
197	95	=	
198	99	PRT	
199	43	RCL	
200	17	17	
201	55	÷	
202	43	RCL	
203	59	59	
204	95	=	
205	99	PRT	Calculate and Print a_{ij}
206	43	RCL	
207	18	18	
208	55	÷	
209	43	RCL	
210	59	59	
211	95	=	
212	99	PRT	
213	43	RCL	
214	19	19	
215	55	÷	
216	43	RCL	
217	59	59	
218	95	=	
219	99	PRT	
220	98	ADV	
221	01	1	
222	93	.	
223	01	1	
224	95	=	
225	91	R/S	
226	76	LBL	
227	12	B	
228	42	STO	X
229	23	23	
230	57	ENG	
231	58	FIX	
232	03	03	
233	04	4	
234	04	4	
235	00	0	
236	00	0	
237	42	STO	
238	02	02	
239	36	PGM	

Step	Code	Key	
240	11	11	
241	71	SBR	
242	90	LST	
243	43	RCL	
244	23	23	
245	99	PRT	
246	05	5	
247	95	=	
248	91	R/S	
249	42	STO	X'
250	24	24	
251	99	PRT	
252	04	4	
253	95	=	
254	91	R/S	
255	42	STO	Y
256	25	25	
257	99	PRT	
258	03	3	
259	95	=	
260	91	R/S	
261	42	STO	Y'
262	26	26	
263	99	PRT	
264	02	2	
265	95	=	
266	91	R/S	
267	42	STO	S
268	27	27	
269	99	PRT	
270	98	ADV	
271	02	2	
272	01	1	
273	04	4	
274	04	4	
275	04	4	
276	05	5	
277	42	STO	
278	02	02	
279	36	PGM	
280	11	11	
281	71	SBR	
282	90	LST	
283	01	1	
284	95	=	
285	91	R/S	
286	42	STO	F^*_{xy}
287	28	28	
288	99	PRT	
289	98	ADV	
290	36	PGM	
291	08	08	F_{ij}
292	71	SBR	
293	98	ADV	
294	02	2	
295	01	1	
296	00	0	
297	00	0	
298	42	STO	
299	02	02	

Step	Code	Key	
300	36	PGM	
301	11	11	
302	71	SBR	
303	90	LST	
304	43	RCL	
305	44	44	
306	99	PRT	
307	43	RCL	
308	45	45	
309	99	PRT	
310	43	RCL	
311	46	46	
312	99	PRT	
313	43	RCL	
314	47	47	
315	99	PRT	
316	43	RCL	
317	48	48	Print F_{ij}
318	99	PRT	
319	43	RCL	
320	49	49	
321	99	PRT	
322	98	ADV	
323	36	PGM	
324	08	08	
325	71	SBR	G_{ij}
326	80	GRD	
327	02	2	
328	02	2	
329	00	0	
330	00	0	
331	42	STO	
332	02	02	
333	36	PGM	
334	11	11	
335	71	SBR	
336	90	LST	
337	43	RCL	
338	16	16	
339	99	PRT	
340	42	STO	
341	44	44	
342	43	RCL	
343	17	17	
344	99	PRT	
345	42	STO	
346	45	45	
347	43	RCL	
348	18	18	
349	99	PRT	Print and Transfer G_{ij}
350	42	STO	
351	46	46	
352	43	RCL	
353	19	19	
354	99	PRT	
355	42	STO	
356	47	47	
357	43	RCL	
358	20	20	
359	99	PRT	

Step	Code	Key	
360	42	STO	
361	48	48	
362	43	RCL	
363	31	31	
364	99	PRT	
365	42	STO	
366	49	49	
367	98	ADV	
368	98	ADV	
369	98	ADV	
370	01	1	
371	93	.	
372	02	2	
373	95	=	
374	91	R/S	
375	76	LBL	
376	13	C	
377	06	6	SI→
378	08	8	Engl.
379	09	9	
380	05	5	
381	35	1/X	
382	49	PRD	
383	30	30	
384	49	PRD	
385	31	31	
386	49	PRD	
387	32	32	
388	49	PRD	
389	33	33	
390	49	PRD	
391	34	34	
392	95	=	
393	03	3	
394	09	9	
395	93	.	
396	04	4	
397	49	PRD	
398	59	59	
399	71	SBR	
400	33	X²	
401	76	LBL	
402	14	D	
403	06	6	Engl→
404	08	8	SI
405	09	9	
406	05	5	
407	49	PRD	
408	30	30	
409	49	PRD	
410	31	31	
411	49	PRD	
412	32	32	
413	49	PRD	
414	33	33	
415	49	PRD	
416	34	34	
417	95	=	
418	03	3	
419	09	9	

Step	Code	Key	
420	93	.	
421	04	4	
422	35	1/X	
423	49	PRD	
424	59	59	
425	76	LBL	
426	33	X²	
427	04	4	
428	01	1	
429	06	6	
430	05	5	
431	42	STO	
432	02	02	
433	36	PGM	
434	11	11	
435	71	SBR	
436	90	LST	
437	43	RCL	
438	30	30	
439	99	PRT	
440	43	RCL	
441	31	31	
442	99	PRT	
443	43	RCL	
444	32	32	
445	99	PRT	
446	43	RCL	
447	33	33	
448	99	PRT	
449	43	RCL	
450	34	34	
451	99	PRT	Print Converted U_i and h_o
452	98	ADV	
453	02	2	
454	03	3	
455	06	6	
456	05	5	
457	42	STO	
458	02	02	
459	36	PGM	
460	11	11	
461	71	SBR	
462	90	LST	
463	43	RCL	
464	59	59	
465	99	PRT	
466	98	ADV	
467	91	R/S	
468	00	0	
469	00	0	
470	00	0	
471	00	0	
472	00	0	
473	00	0	
474	00	0	
475	00	0	
476	00	0	
477	00	0	
478	00	0	
479	00	0	

COMBO 2: In-Plane Stiffness and Strength without Printer

Step	Code	Key	
000	76	LBL	
001	11	A	
002	42	STO	
003	05	05	n
004	65	×	
005	43	RCL	
006	59	59	
007	95	=	
008	42	STO	h
009	09	09	
010	57	ENG	
011	58	FIX	
012	03	03	
013	00	0	
014	36	PGM	$V_{iA}=$
015	12	12	
016	71	SBR	0
017	61	GTO	
018	93	.	
019	05	5	
020	49	PRD	n/2
021	05	05	
022	43	RCL	t
023	05	05	
024	91	R/S	
025	94	+/-	
026	42	STO	θ
027	35	35	
028	01	1	
029	42	STO	
030	04	04	
031	44	SUM	
032	36	36	
033	36	PGM	ΣV_{iA}
034	12	12	
035	71	SBR	
036	71	SBR	
037	97	DSZ	
038	05	05	
039	00	00	
040	22	22	
041	76	LBL	
042	16	A'	
043	43	RCL	cot
044	59	59	
045	65	×	
046	02	2	
047	95	=	
048	36	PGM	
049	12	12	V_{iA}
050	71	SBR	
051	61	GTO	
052	36	PGM	
053	11	11	A_{ij}
054	71	SBR	
055	23	LNX	
056	36	PGM	
057	11	11	a_{ij}
058	71	SBR	
059	35	1/X	
060	43	RCL	
061	09	09	
062	35	1/X	
063	42	STO	
064	08	08	
065	55	÷	
066	43	RCL	
067	16	16	
068	95	=	E_1^o
069	91	R/S	
070	43	RCL	
071	08	08	
072	55	÷	
073	43	RCL	
074	17	17	
075	95	=	E_2^o
076	91	R/S	
077	43	RCL	
078	18	18	
079	55	÷	
080	43	RCL	
081	16	16	
082	95	=	
083	94	+/-	ν_{21}^o
084	91	R/S	
085	43	RCL	
086	08	08	
087	55	÷	
088	43	RCL	
089	19	19	
090	95	=	E_6^o
091	91	R/S	
092	71	SBR	
093	52	EE	
094	76	LBL	
095	17	B'	
096	43	RCL	
097	10	10	
098	91	R/S	
099	43	RCL	
100	11	11	
101	91	R/S	
102	43	RCL	
103	12	12	
104	91	R/S	
105	43	RCL	
106	13	13	A_{ij}
107	91	R/S	
108	43	RCL	
109	14	14	
110	91	R/S	
111	43	RCL	
112	15	15	Display
113	91	R/S	
114	43	RCL	
115	16	16	
116	91	R/S	
117	43	RCL	
118	17	17	
119	91	R/S	
120	43	RCL	
121	18	18	
122	91	R/S	
123	43	RCL	a_{ij}
124	19	19	
125	91	R/S	
126	43	RCL	
127	20	20	
128	91	R/S	
129	43	RCL	
130	21	21	Display
131	91	R/S	
132	71	SBR	
133	52	EE	
134	76	LBL	
135	18	C'	
136	43	RCL	
137	10	10	
138	55	÷	
139	43	RCL	
140	09	09	
141	95	=	
142	91	R/S	
143	43	RCL	
144	11	11	
145	55	÷	
146	43	RCL	
147	09	09	
148	95	=	
149	91	R/S	
150	43	RCL	
151	12	12	
152	55	÷	
153	43	RCL	
154	09	09	
155	95	=	
156	91	R/S	
157	43	RCL	
158	13	13	
159	55	÷	
160	43	RCL	
161	09	09	
162	95	=	
163	91	R/S	
164	43	RCL	
165	14	14	
166	55	÷	A^*_{ij}
167	43	RCL	
168	09	09	
169	95	=	
170	91	R/S	Display
171	43	RCL	
172	15	15	
173	55	÷	
174	43	RCL	
175	09	09	
176	95	=	
177	91	R/S	
178	43	RCL	
179	16	16	
180	65	×	
181	43	RCL	
182	09	09	
183	95	=	
184	91	R/S	
185	43	RCL	
186	17	17	
187	65	×	
188	43	RCL	
189	09	09	
190	95	=	
191	91	R/S	
192	43	RCL	
193	18	18	
194	65	×	
195	43	RCL	
196	09	09	
197	95	=	
198	91	R/S	
199	43	RCL	
200	19	19	
201	65	×	
202	43	RCL	
203	09	09	
204	95	=	
205	91	R/S	
206	43	RCL	
207	20	20	
208	65	×	
209	43	RCL	
210	09	09	a^*_{ij}
211	95	=	
212	91	R/S	
213	43	RCL	
214	21	21	Display
215	65	×	
216	43	RCL	
217	09	09	
218	95	=	
219	91	R/S	
220	76	LBL	
221	52	EE	
222	06	6	
223	93	.	
224	01	1	
225	95	=	
226	91	R/S	
227	76	LBL	
228	12	B	
229	42	STO	N_1
230	26	26	
231	06	6	
232	93	.	
233	02	2	
234	95	=	
235	91	R/S	
236	42	STO	
237	27	27	N_2
238	06	6	
239	93	.	

Step	Code	Key	
240	06	6	
241	95	=	
242	91	R/S	
243	42	STO	N_6
244	28	28	
245	36	PGM	
246	11	11	
247	71	SBR	a_{ij}
248	35	1/X	
249	36	PGM	
250	10	10	ϵ_i°
251	71	SBR	
252	89	π	
253	76	LBL	
254	33	X²	
255	36	PGM	
256	10	10	
257	71	SBR	p,q,r
258	34	ΓX	
259	43	RCL	
260	44	44	
261	42	STO	
262	16	16	
263	43	RCL	
264	45	45	
265	42	STO	
266	17	17	
267	43	RCL	
268	46	46	
269	42	STO	
270	18	18	
271	43	RCL	
272	47	47	G_{ij}
273	42	STO	
274	19	19	
275	43	RCL	
276	48	48	Transfer
277	42	STO	
278	20	20	
279	43	RCL	
280	49	49	
281	42	STO	
282	21	21	
283	71	SBR	
284	24	CE	
285	76	LBL	
286	10	E'	
287	43	RCL	
288	53	53	I_6
289	91	R/S	
290	43	RCL	
291	54	54	
292	33	X²	
293	85	+	
294	43	RCL	
295	55	55	
296	33	X²	
297	95	=	
298	34	ΓX	R_6
299	91	R/S	

Step	Code	Key	
300	76	LBL	θ
301	24	CE	
302	06	6	propagator
303	00	0	
304	95	=	
305	91	R/S	
306	76	LBL	
307	13	C	θ_t
308	42	STO	
309	41	41	
310	36	PGM	
311	10	10	$\epsilon_i(\theta)$
312	71	SBR	
313	54	)	
314	00	0	
315	42	STO	
316	26	26	
317	42	STO	$\epsilon_i^{\prime\prime}=0$
318	27	27	
319	42	STO	
320	28	28	
321	36	PGM	R_t
322	08	08	
323	71	SBR	R_t'
324	30	TAN	
325	43	RCL	
326	06	06	
327	91	R/S	Display R_t', R_t''
328	43	RCL	
329	07	07	
330	91	R/S	
331	71	SBR	
332	24	CE	
333	76	LBL	
334	14	D	
335	43	RCL	
336	06	06	
337	55	÷	
338	43	RCL	
339	09	09	
340	95	=	
341	91	R/S	σ_t°
342	43	RCL	
343	07	07	
344	55	÷	
345	43	RCL	
346	09	09	
347	95	=	$\sigma_t^{\circ\prime}$
348	91	R/S	
349	71	SBR	
350	24	CE	
351	76	LBL	
352	15	E	
353	42	STO	ϵ_1°
354	23	23	
355	08	8	
356	93	.	
357	01	1	
358	95	=	
359	91	R/S	

Step	Code	Key	
360	42	STO	ϵ_2°
361	24	24	
362	08	8	
363	93	.	
364	02	2	
365	95	=	
366	91	R/S	
367	42	STO	ϵ_6°
368	25	25	
369	71	SBR	
370	33	X²	
371	76	LBL	
372	19	D'	Unit Ply Data
373	57	ENG	
374	58	FIX	
375	03	03	
376	43	RCL	
377	59	59	
378	42	STO	
379	09	09	
380	42	STO	
381	36	36	
382	42	STO	
383	37	37	
384	42	STO	
385	39	39	
386	00	0	
387	42	STO	
388	38	38	
389	42	STO	
390	40	40	
391	61	GTO	
392	00	00	
393	52	52	
394	00	0	
395	00	0	
396	00	0	
397	00	0	
398	00	0	
399	00	0	
400	00	0	
401	00	0	
402	00	0	
403	00	0	
404	00	0	
405	00	0	
406	00	0	
407	00	0	
408	00	0	
409	00	0	
410	00	0	
411	00	0	
412	00	0	
413	00	0	
414	00	0	
415	00	0	
416	00	0	
417	00	0	
418	00	0	
419	00	0	

COMBO 2P: In-Plane Stiffness and Strength with Printer

Step	Code	Key	
000	76	LBL	
001	11	A	
002	42	STO	
003	05	05	n
004	99	PRT	
005	98	ADV	
006	65	×	
007	43	RCL	
008	59	59	
009	95	=	
010	42	STO	h
011	09	09	
012	57	ENG	
013	58	FIX	
014	03	03	
015	00	0	
016	36	PGM	
017	12	12	V_{iA}^2
018	71	SBR	0
019	61	GTO	
020	93	.	
021	05	5	
022	49	PRD	n/2
023	05	05	
024	43	RCL	t
025	05	05	
026	91	R/S	
027	99	PRT	
028	94	+/-	
029	42	STO	θ_t
030	35	35	
031	01	1	
032	42	STO	
033	04	04	
034	44	SUM	
035	36	36	
036	36	PGM	
037	12	12	ΣV_{iA}
038	71	SBR	
039	71	SBR	
040	97	DSZ	
041	05	05	
042	00	00	
043	24	24	
044	71	SBR	
045	53	(	
046	76	LBL	
047	16	A'	Core
048	01	1	
049	05	5	
050	03	3	
051	05	5	
052	42	STO	
053	02	02	
054	36	PGM	
055	11	11	
056	71	SBR	
057	90	LST	
058	43	RCL	
059	05	05	
060	99	PRT	
061	76	LBL	
062	53	(	
063	43	RCL	
064	59	59	
065	65	×	
066	02	2	
067	95	=	
068	36	PGM	
069	12	12	V_{iA}
070	71	SBR	
071	61	GTO	
072	03	3	
073	06	6	
074	04	4	
075	05	5	
076	03	3	
077	00	0	
078	42	STO	
079	02	02	
080	36	PGM	
081	11	11	
082	71	SBR	
083	90	LST	
084	98	ADV	
085	36	PGM	
086	11	11	A_{ij}
087	71	SBR	
088	23	LNX	
089	36	PGM	
090	11	11	a_{ij}
091	71	SBR	
092	35	1/X	
093	01	1	
094	07	7	
095	05	5	
096	01	1	
097	42	STO	
098	02	02	
099	36	PGM	
100	11	11	
101	71	SBR	
102	90	LST	
103	43	RCL	
104	09	09	
105	35	1/X	
106	42	STO	
107	08	08	E_1^0
108	55	÷	
109	43	RCL	
110	16	16	
111	95	=	
112	99	PRT	
113	43	RCL	
114	08	08	
115	55	÷	E_2^0
116	43	RCL	
117	17	17	
118	95	=	
119	99	PRT	
120	43	RCL	
121	18	18	
122	55	÷	
123	43	RCL	
124	16	16	ν_{21}^0
125	95	=	
126	94	+/-	
127	99	PRT	
128	43	RCL	
129	08	08	
130	55	÷	
131	43	RCL	E_6^0
132	19	19	
133	95	=	
134	99	PRT	
135	98	ADV	
136	01	1	
137	03	3	
138	00	0	
139	00	0	
140	42	STO	
141	02	02	
142	36	PGM	
143	11	11	
144	71	SBR	
145	90	LST	
146	43	RCL	
147	10	10	
148	99	PRT	
149	43	RCL	
150	11	11	
151	99	PRT	
152	43	RCL	
153	12	12	Print A_{ij}
154	99	PRT	
155	43	RCL	
156	13	13	
157	99	PRT	
158	43	RCL	
159	14	14	
160	99	PRT	
161	43	RCL	
162	15	15	
163	99	PRT	
164	98	ADV	
165	01	1	
166	03	3	
167	02	2	
168	04	4	
169	42	STO	
170	02	02	
171	36	PGM	
172	11	11	
173	71	SBR	
174	90	LST	Print a_{ij}
175	43	RCL	
176	16	16	
177	99	PRT	
178	43	RCL	
179	17	17	
180	99	PRT	
181	43	RCL	
182	18	18	
183	99	PRT	
184	43	RCL	
185	19	19	
186	99	PRT	
187	43	RCL	
188	20	20	
189	99	PRT	
190	43	RCL	
191	21	21	
192	99	PRT	
193	98	ADV	
194	01	1	
195	03	3	
196	05	5	
197	01	1	
198	42	STO	
199	02	02	
200	36	PGM	
201	11	11	
202	71	SBR	
203	90	LST	
204	61	GTO	
205	02	02	
206	15	15	
207	76	LBL	
208	23	LNX	
209	55	÷	A_{ij}/h
210	43	RCL	
211	09	09	
212	95	=	
213	99	PRT	
214	92	RTN	
215	43	RCL	
216	10	10	
217	71	SBR	
218	23	LNX	
219	43	RCL	
220	11	11	
221	71	SBR	
222	23	LNX	
223	43	RCL	
224	12	12	
225	71	SBR	
226	23	LNX	
227	43	RCL	Print A^*_{ij}
228	13	13	
229	71	SBR	
230	23	LNX	
231	43	RCL	
232	14	14	
233	71	SBR	
234	23	LNX	
235	43	RCL	
236	15	15	
237	71	SBR	
238	23	LNX	
239	98	ADV	

240	01	1	
241	03	3	
242	05	5	
243	01	1	
244	02	2	
245	04	4	
246	42	STO	
247	02	02	
248	36	PGM	
249	11	11	
250	71	SBR	
251	90	LST	
252	61	GTO	
253	02	02	
254	63	63	
255	76	LBL	
256	22	INV	
257	65	×	
258	43	RCL	a_{ijh}
259	09	09	
260	95	=	
261	99	PRT	
262	92	RTN	
263	43	RCL	
264	16	16	
265	71	SBR	
266	22	INV	
267	43	RCL	
268	17	17	
269	71	SBR	
270	22	INV	
271	43	RCL	
272	18	18	
273	71	SBR	
274	22	INV	
275	43	RCL	
276	19	19	
277	71	SBR	
278	22	INV	
279	43	RCL	
280	20	20	Print a^*_{ij}
281	71	SBR	
282	22	INV	
283	43	RCL	
284	21	21	
285	71	SBR	
286	22	INV	
287	98	ADV	
288	06	6	
289	93	.	
290	01	1	
291	95	=	
292	91	R/S	
293	76	LBL	
294	12	B	
295	42	STO	N_1
296	26	26	
297	03	3	
298	01	1	
299	00	0	

300	00	0	
301	42	STO	
302	02	02	
303	36	PGM	
304	11	11	
305	71	SBR	
306	90	LST	
307	43	RCL	
308	26	26	
309	99	PRT	
310	06	6	
311	93	.	
312	02	2	
313	95	=	
314	91	R/S	
315	99	PRT	
316	42	STO	N_2
317	27	27	
318	06	6	
319	93	.	
320	06	6	
321	95	=	
322	91	R/S	
323	99	PRT	
324	98	ADV	
325	42	STO	N_6
326	28	28	
327	36	PGM	
328	11	11	
329	71	SBR	a_{ij}
330	35	1/X	
331	36	PGM	
332	10	10	ϵ_i^0
333	71	SBR	
334	89	π	
335	36	PGM	
336	10	10	p,q,r
337	71	SBR	
338	34	√X	
339	05	5	
340	04	4	
341	02	2	
342	04	4	
343	42	STO	
344	02	02	
345	36	PGM	
346	11	11	
347	71	SBR	
348	90	LST	
349	43	RCL	
350	53	53	I_ϵ
351	99	PRT	
352	43	RCL	
353	54	54	
354	33	X²	
355	85	+	R_ϵ
356	43	RCL	
357	55	55	
358	33	X²	
359	95	=	

360	34	√X	
361	99	PRT	
362	98	ADV	
363	43	RCL	
364	44	44	
365	42	STO	
366	16	16	
367	43	RCL	
368	45	45	
369	42	STO	
370	17	17	
371	43	RCL	
372	46	46	
373	42	STO	
374	18	18	
375	43	RCL	
376	47	47	
377	42	STO	
378	19	19	
379	43	RCL	Transfer G_{ij}
380	48	48	
381	42	STO	
382	20	20	
383	43	RCL	
384	49	49	
385	42	STO	
386	21	21	
387	76	LBL	
388	24	CE	θ
389	06	6	prompter
390	00	0	
391	95	=	
392	91	R/S	
393	76	LBL	
394	13	C	
395	42	STO	θ_t
396	41	41	
397	06	6	
398	00	0	
399	00	0	
400	00	0	
401	42	STO	
402	02	02	
403	36	PGM	
404	11	11	
405	71	SBR	
406	90	LST	
407	43	RCL	
408	41	41	
409	99	PRT	
410	98	ADV	
411	36	PGM	
412	10	10	$\epsilon_i(\theta_0)$
413	71	SBR	
414	54	)	
415	00	0	
416	42	STO	
417	26	26	$\epsilon_i^N = 0$
418	42	STO	
419	27	27	

420	42	STO	
421	28	28	
422	36	PGM	R_t
423	08	08	
424	71	SBR	R_t'
425	30	TAN	
426	03	3	
427	05	5	
428	00	0	
429	00	0	
430	42	STO	
431	02	02	
432	36	PGM	
433	11	11	
434	71	SBR	
435	90	LST	
436	43	RCL	
437	06	06	Print R_t, R_t'
438	99	PRT	
439	43	RCL	
440	07	07	
441	99	PRT	
442	98	ADV	
443	07	7	
444	07	7	
445	00	0	
446	00	0	
447	42	STO	
448	02	02	
449	36	PGM	
450	11	11	
451	71	SBR	
452	90	LST	
453	43	RCL	
454	06	06	Calculate & Print σ_t^0
455	55	÷	
456	43	RCL	
457	09	09	
458	95	=	
459	99	PRT	
460	43	RCL	
461	07	07	
462	55	÷	
463	43	RCL	$\tau_t^{0\prime}$
464	09	09	
465	95	=	
466	99	PRT	
467	98	ADV	
468	71	SBR	
469	24	CE	
470	00	0	
471	00	0	
472	00	0	
473	00	0	
474	00	0	
475	00	0	
476	00	0	
477	00	0	
478	00	0	
479	00	0	

COMBO 3: Flexural Stiffness and Strength without Printer

Step	Code	Key	
000	76	LBL	
001	11	A	
002	42	STO	n
003	05	05	
004	65	×	
005	43	RCL	
006	59	59	
007	95	=	
008	42	STO	h
009	09	09	
010	57	ENG	
011	58	FIX	
012	03	03	
013	00	0	
014	36	PGM	$V_{i0} = 0$
015	12	12	
016	71	SBR	
017	61	GTO	
018	43	RCL	
019	05	05	
020	55	÷	
021	02	2	
022	95	=	
023	42	STO	n/2
024	05	05	
025	42	STO	t
026	06	06	
027	75	-	
028	01	1	
029	95	=	
030	42	STO	
031	07	07	
032	43	RCL	
033	05	05	
034	91	R/S	
035	94	+/-	
036	42	STO	
037	35	35	
038	43	RCL	
039	06	06	
040	45	Y^x	
041	03	3	
042	75	-	
043	43	RCL	
044	07	07	
045	45	Y^x	
046	03	3	
047	95	=	
048	42	STO	ΣV_{iD}
049	04	04	
050	44	SUM	
051	36	36	
052	36	PGM	
053	12	12	
054	71	SBR	
055	71	SBR	
056	97	DSZ	
057	05	05	
058	00	00	
059	32	32	

Step	Code	Key	
060	76	LBL	Core
061	16	A'	
062	43	RCL	
063	59	59	
064	45	Y^x	
065	03	3	
066	65	×	
067	02	2	
068	55	÷	
069	03	3	
070	95	=	
071	36	PGM	
072	12	12	V_{iD}
073	71	SBR	
074	61	GTO	
075	36	PGM	
076	11	11	D_{ij}
077	71	SBR	
078	23	LNX	
079	36	PGM	
080	11	11	d_{ij}
081	71	SBR	
082	35	1/X	
083	01	1	
084	02	2	
085	55	÷	
086	43	RCL	
087	09	09	
088	45	Y^x	
089	03	3	
090	95	=	
091	42	STO	
092	08	08	
093	55	÷	E_1^f
094	43	RCL	
095	16	16	
096	95	=	
097	91	R/S	
098	43	RCL	
099	08	08	
100	55	÷	
101	43	RCL	
102	17	17	E_2^f
103	95	=	
104	91	R/S	
105	43	RCL	
106	18	18	
107	55	÷	
108	43	RCL	
109	16	16	
110	95	=	ν_{21}^f
111	94	+/-	
112	91	R/S	
113	43	RCL	
114	08	08	
115	55	÷	
116	43	RCL	
117	19	19	E_6^f
118	95	=	
119	91	R/S	

Step	Code	Key	
120	71	SBR	
121	52	EE	
122	76	LBL	
123	17	B'	
124	43	RCL	
125	10	10	
126	91	R/S	
127	43	RCL	
128	11	11	
129	91	R/S	
130	43	RCL	
131	12	12	D_{ij}
132	91	R/S	
133	43	RCL	
134	13	13	
135	91	R/S	
136	43	RCL	
137	14	14	
138	91	R/S	
139	43	RCL	
140	15	15	
141	91	R/S	
142	43	RCL	
143	16	16	
144	91	R/S	
145	43	RCL	
146	17	17	
147	91	R/S	
148	43	RCL	
149	18	18	d_{ij}
150	91	R/S	
151	43	RCL	
152	19	19	
153	91	R/S	
154	43	RCL	
155	20	20	
156	91	R/S	
157	43	RCL	
158	21	21	
159	91	R/S	
160	71	SBR	
161	52	EE	
162	76	LBL	
163	18	C'	
164	43	RCL	
165	10	10	
166	65	×	
167	43	RCL	
168	08	08	
169	95	=	
170	91	R/S	
171	43	RCL	
172	11	11	
173	65	×	
174	43	RCL	
175	08	08	
176	95	=	
177	91	R/S	
178	43	RCL	
179	12	12	

Step	Code	Key	
180	65		
181	43	RCL	
182	08	08	
183	95	=	
184	91	R/S	
185	43	RCL	
186	13	13	
187	65		
188	43	RCL	
189	08	08	
190	95	=	
191	91	R/S	
192	43	RCL	
193	14	14	
194	65	×	D^*_{ij}
195	43	RCL	
196	08	08	
197	95	=	
198	91	R/S	
199	43	RCL	
200	15	15	
201	65	×	
202	43	RCL	
203	08	08	
204	95	=	
205	91	R/S	
206	43	RCL	
207	16	16	
208	55	÷	
209	43	RCL	
210	08	08	
211	95	=	
212	91	R/S	
213	43	RCL	
214	17	17	
215	55	÷	
216	43	RCL	
217	08	08	
218	95	=	
219	91	R/S	
220	43	RCL	
221	18	18	
222	55	÷	
223	43	RCL	
224	08	08	
225	95	=	d^*_{ij}
226	91	R/S	
227	43	RCL	
228	19	19	
229	55	÷	
230	43	RCL	
231	08	08	
232	95	=	
233	91	R/S	
234	43	RCL	
235	20	20	
236	55	÷	
237	43	RCL	
238	08	08	
239	95	=	

240	91	R/S	
241	43	RCL	
242	21	21	
243	55	÷	
244	43	RCL	
245	08	08	
246	95	=	
247	91	R/S	
248	76	LBL	
249	52	EE	
250	06	6	
251	93	.	
252	01	1	
253	95	=	
254	91	R/S	
255	76	LBL	
256	12	B	
257	42	STO	M_1
258	26	26	
259	06	6	
260	93	.	
261	02	2	
262	95	=	
263	91	R/S	
264	42	STO	M_2
265	27	27	
266	06	6	
267	93	.	
268	06	6	
269	95	=	
270	91	R/S	
271	42	STO	M_6
272	28	28	
273	36	PGM	
274	11	11	d_{ij}
275	71	SBR	
276	35	1/X	
277	36	PGM	
278	10	10	k_i
279	71	SBR	
280	89	π	
281	36	PGM	
282	10	10	p,q,r
283	71	SBR	
284	34	√X	
285	43	RCL	Transfer G_{ij}
286	44	44	
287	42	STO	
288	16	16	
289	43	RCL	
290	45	45	
291	42	STO	
292	17	17	
293	43	RCL	
294	46	46	
295	42	STO	
296	18	18	
297	43	RCL	
298	47	47	
299	42	STO	
300	19	19	
301	43	RCL	
302	48	48	
303	42	STO	
304	20	20	
305	43	RCL	
306	49	49	
307	42	STO	
308	21	21	
309	76	LBL	
310	24	CE	θ prompter
311	06	6	
312	00	0	
313	95	=	
314	91	R/S	
315	76	LBL	
316	13	C	
317	42	STO	θ_t
318	41	41	
319	03	3	
320	07	7	
321	95	=	
322	91	R/S	
323	42	STO	t
324	05	05	
325	36	PGM	
326	10	10	$k_i(\theta_t)$
327	71	SBR	
328	54	)	
329	43	RCL	
330	05	05	
331	65	×	
332	43	RCL	
333	59	59	z_t
334	95	=	
335	49	PRD	
336	23	23	
337	49	PRD	
338	24	24	$\epsilon_i(\theta_t)$
339	49	PRD	
340	25	25	
341	00	0	
342	42	STO	
343	26	26	$\epsilon_i^N = 0$
344	42	STO	
345	27	27	
346	42	STO	
347	28	28	
348	36	PGM	R_t
349	08	08	
350	71	SBR	R_t'
351	30	TAN	
352	43	RCL	
353	06	06	
354	91	R/S	Display R_t, R_t'
355	43	RCL	
356	07	07	
357	91	R/S	
358	71	SBR	
359	24	CE	
360	76	LBL	
361	14	D	
362	43	RCL	
363	06	06	
364	55	÷	
365	43	RCL	
366	09	09	
367	33	X²	
368	65	×	
369	06	6	σ_t^f
370	95	=	
371	91	R/S	
372	55	÷	
373	43	RCL	
374	06	06	
375	65	×	
376	43	RCL	
377	07	07	$\sigma_t^{f'}$
378	95	=	
379	91	R/S	
380	71	SBR	
381	24	CE	
382	00	0	
383	00	0	
384	00	0	
385	00	0	
386	00	0	
387	00	0	
388	00	0	
389	00	0	
390	00	0	
391	00	0	
392	00	0	
393	00	0	
394	00	0	
395	00	0	
396	00	0	
397	00	0	
398	00	0	
399	00	0	
400	00	0	
401	00	0	
402	00	0	
403	00	0	
404	00	0	
405	00	0	
406	00	0	
407	00	0	
408	00	0	
409	00	0	
410	00	0	
411	00	0	
412	00	0	
413	00	0	
414	00	0	
415	00	0	
416	00	0	
417	00	0	
418	00	0	
419	00	0	

COMBO 3P: Flexural Stiffness and Strength with Printer

```
000  76  LBL
001  11  A
002  42  STO   n
003  05  05
004  99  PRT
005  98  ADV
006  [illegible]
007  43  RCL
008  59  59
009  95  =
010  42  STO   h
011  09  09
012  57  ENG
013  58  FIX
014  03  03
015  00  0
016  36  PGM
017  12  12    ViD=0
018  71  SBR
019  61  GTO
020  43  RCL
021  05  05
022  55  ÷
023  02  2
024  95  =
025  42  STO   n/2
026  05  05
027  42  STO   t
028  06  06
029  75  -
030  01  1
031  95  =
032  42  STO
033  07  07
034  43  RCL
035  05  05
036  91  R/S
037  99  PRT
038  94  +/-
039  42  STO
040  35  35
041  43  RCL
042  06  06
043  45  Y^X
044  03  3
045  75  -
046  43  RCL
047  07  07
048  45  Y^X
049  03  3
050  95  =
051  42  STO   ΣViD
052  04  04
053  44  SUM
054  36  36
055  36  PGM
056  12  12
057  71  SBR
058  71  SBR
059  97  DSZ

060  05  05
061  00  00
062  34  34
063  71  SBR
064  53  (
065  76  LBL   Core
066  16  A'
067  01  1
068  05  5
069  03  3
070  05  5
071  42  STO
072  02  02
073  36  PGM
074  11  11
075  71  SBR
076  90  LST
077  43  RCL
078  05  05
079  99  PRT
080  76  LBL
081  53  (
082  43  RCL
083  59  59
084  45  Y^X
085  03  3
086  65  ×
087  02  2
088  55  ÷
089  03  3
090  95  =
091  36  PGM
092  12  12    ViD
093  71  SBR
094  61  GTO
095  03  3
096  06  6
097  04  4
098  05  5
099  03  3
100  00  0
101  42  STO
102  02  02
103  36  PGM
104  11  11
105  71  SBR
106  90  LST
107  98  ADV
108  36  PGM
109  11  11
110  71  SBR   Dij
111  23  LNX
112  36  PGM
113  11  11
114  71  SBR   dij
115  35  1/X
116  01  1
117  07  7
118  05  5
119  01  1

120  42  STO
121  02  02
122  36  PGM
123  11  11
124  71  SBR
125  [illegible]
126  [illegible]
127  [illegible]
128  55  ÷
129  43  RCL
130  09  09
131  45  Y^X
132  03  3
133  95  =
134  42  STO
135  08  08
136  55  ÷
137  43  RCL
138  16  16    E1f
139  95  =
140  99  PRT
141  43  RCL
142  08  08
143  55  ÷
144  43  RCL
145  17  17    E2f
146  95  =
147  99  PRT
148  43  RCL
149  18  18
150  55  ÷
151  43  RCL
152  16  16    ν21f
153  95  =
154  94  +/-
155  99  PRT
156  43  RCL
157  08  08
158  55  ÷
159  43  RCL
160  19  19    E6f
161  95  =
162  99  PRT
163  98  ADV
164  01  1
165  06  6
166  00  0
167  00  0
168  42  STO
169  02  02
170  36  PGM
171  11  11
172  71  SBR
173  90  LST
174  43  RCL
175  10  10
176  99  PRT
177  43  RCL
178  11  11
179  99  PRT

180  [illegible]
181  [illegible]
182  [illegible]
183  [illegible]
184  [illegible]
185  [illegible]
186  [illegible]
187  [illegible]
188  [illegible]
189  43  RCL
190  [illegible]
191  99  PRT   Print Dij
192  98  ADV
193  43  RCL
194  [illegible]
195  99  PRT
196  43  RCL
197  17  17
198  99  PRT
199  43  RCL
200  18  18
201  99  PRT
202  43  RCL
203  19  19
204  99  PRT
205  43  RCL
206  20  20
207  99  PRT
208  43  RCL
209  21  21
210  99  PRT   Print dij
211  98  ADV
212  01  1
213  06  6
214  05  5
215  01  1
216  42  STO
217  02  02
218  36  PGM
219  11  11
220  71  SBR
221  90  LST
222  61  GTO
223  02  02
224  33  33
225  76  LBL
226  23  LNX   12Dij/h^3
227  65  ×
228  43  RCL
229  08  08
230  95  =
231  99  PRT
232  92  RTN
233  43  RCL
234  10  10
235  71  SBR
236  23  LNX
237  43  RCL
238  11  11
239  71  SBR
```

240	23	LNX	
241	43	RCL	
242	12	12	
243	71	SBR	
244	23	LNX	
245	43	RCL	
246	13	13	
247	71	SBR	
248	23	LNX	D_{ij}^*
249	43	RCL	
250	14	14	
251	71	SBR	
252	23	LNX	
253	43	RCL	
254	15	15	
255	71	SBR	
256	23	LNX	
257	98	ADV	
258	61	GTO	
259	02	02	
260	69	69	
261	76	LBL	
262	22	INV	$\frac{d_{ij}k^3}{12}$
263	55	÷	
264	43	RCL	
265	08	08	
266	95	=	
267	99	PRT	
268	92	RTN	
269	43	RCL	
270	16	16	
271	71	SBR	
272	22	INV	
273	43	RCL	
274	17	17	
275	71	SBR	
276	22	INV	
277	43	RCL	
278	18	19	
279	71	SBR	
280	22	INV	
281	43	RCL	d_{ij}^*
282	19	19	
283	71	SBR	
284	22	INV	
285	43	RCL	
286	20	20	
287	71	SBR	
288	22	INV	
289	43	RCL	
290	21	21	
291	71	SBR	
292	22	INV	
293	98	ADV	
294	06	6	
295	93	.	
296	01	1	
297	95	=	
298	91	R/S	
299	76	LBL	

300	12	B	
301	42	STO	M_1
302	26	26	
303	03	3	
304	00	0	
305	00	0	
306	00	0	
307	42	STO	
308	02	02	
309	36	PGM	
310	11	11	
311	71	SBR	
312	90	LST	
313	43	RCL	
314	26	26	
315	99	PRT	
316	06	6	
317	93	.	
318	02	2	
319	95	=	
320	91	R/S	
321	99	PRT	
322	42	STO	M_2
323	27	27	
324	06	6	
325	93	.	
326	06	6	
327	95	=	
328	91	R/S	
329	99	PRT	
330	98	ADV	
331	42	STO	M_6
332	28	28	
333	36	PGM	
334	11	11	
335	71	SBR	d_{ij}
336	35	1/X	
337	36	PGM	
338	10	10	
339	71	SBR	k_i
340	89	π	
341	36	PGM	
342	10	10	
343	71	SBR	p,q,r
344	34	√X	
345	43	RCL	
346	44	44	
347	42	STO	
348	16	16	
349	43	RCL	
350	45	45	Transfer G_{it}
351	42	STO	
352	17	17	
353	43	RCL	
354	46	46	
355	42	STO	
356	18	18	
357	43	RCL	
358	47	47	
359	42	STO	

360	19	19	
361	43	RCL	
362	48	48	
363	42	STO	
364	20	20	
365	43	RCL	
366	49	49	
367	42	STO	
368	21	21	
369	76	LBL	
370	24	CE	
371	06	6	θ prompter
372	00	0	
373	95	=	
374	91	R/S	
375	76	LBL	
376	13	C	
377	42	STO	θ_t
378	41	41	
379	06	6	
380	00	0	
381	05	5	
382	07	7	
383	03	3	
384	07	7	
385	42	STO	
386	02	02	
387	36	PGM	
388	11	11	
389	71	SBR	
390	90	LST	
391	43	RCL	
392	41	41	
393	99	PRT	
394	03	3	
395	07	7	
396	95	=	
397	91	R/S	
398	42	STO	t
399	05	05	
400	99	PRT	
401	98	ADV	
402	36	PGM	
403	10	10	$k_i(\theta_t)$
404	71	SBR	
405	54	)	
406	43	RCL	
407	05	05	
408	65	×	
409	43	RCL	z_t
410	59	59	
411	95	=	
412	49	PRD	
413	23	23	
414	49	PRD	
415	24	24	$\epsilon_i(\theta_t)$
416	49	PRD	
417	25	25	
418	00	0	
419	42	STO	

420	[illegible]	[illegible]	
421	4[illegible]	[illegible]	
422	42	[illegible]	$\epsilon_i^N = 0$
423	[illegible]	[illegible]	
424	[illegible]	[illegible]	
425	[illegible]	PRT	R_t
426	06	[illegible]	
427	71	SBR	R_t'
428	30	[illegible]	
429	03	3	
430	05	5	
431	00	0	
432	00	0	
433	42	STO	
434	02	02	
435	36	PGM	
436	11	11	
437	71	SBR	
438	90	LST	
439	43	RCL	Print R_t, R_t'
440	06	06	
441	99	PRT	
442	43	RCL	
443	07	07	
444	99	PRT	
445	98	ADV	
446	07	7	
447	07	7	
448	00	0	
449	00	0	
450	42	STO	
451	02	02	
452	36	PGM	
453	11	11	
454	71	SBR	
455	90	LST	
456	43	RCL	
457	06	06	
458	55	÷	
459	43	RCL	
460	09	09	
461	33	X²	
462	65	×	σ_t^f
463	06	6	
464	95	=	
465	99	PRT	
466	55	÷	
467	43	RCL	
468	06	06	
469	65	×	
470	43	RCL	$\sigma_t^{f'}$
471	07	07	
472	95	=	
473	99	PRT	
474	98	ADV	
475	71	SBR	
476	24	CE	
477	00	0	
478	00	0	
479	00	0	

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